THE UNIVERSITY OF ALBERTA

COMPARATIVE EFFECTS OF CERTAIN HERBICIDES ON ASPEN AND BALSAM POPLAR

A DISSERTATION
SUBMITTED TO THE FACULTY OF GRADUATE STUDIES
IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR
THE DEGREE OF MASTER OF SCIENCE

DEPARTMENT OF PLANT SCIENCE

by

TZE-SEN DAI

EDMONTON, ALBERTA
SEPTEMBER 1966

THE UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled "Comparative Effects of Certain Herbicides on Aspen and Balsam Poplar" submitted by Tze-sen Dai, B.Sc., in partial fulfilment of the requirements for the degree of Master of Science.

ABSTRACT

Two formulations of picloram and seven types of chlorinated phenoxy acid herbicides were used in studies of their toxicity to growth of aspen poplar (Populus tremuloides Michx.) and balsam poplar (P. balsamifera L.) stem cuttings and saplings in the laboratory and greenhouse and established natural stands in the field. Some comparisons included added surfactants (Atlox 209 and 210) at 0.25% to 1% by volume of the spray solutions. By themselves they were non-toxic to vegetation.

In combination with the herbicides, Atlox 210 was superior to Atlox 209 in increasing visible toxic effects. Maximum results were associated with use of the 1% concentration but were not statistically significantly superior to results from use of the smaller amounts of added surfactant.

Ester formulations of 2,4-D and 2,4,5-T were faster and more effective than other formulations of 2,4-D for killing of foliage of both tree species. Visible response from translocation of the esters, however, was less than it was from the other formulations tested with cuttings or with saplings. Added surfactant had a relatively small effect in enhancement of toxicity of all ester formulations.

In some cases ester formulations of silvex and 2,4,5-T were slightly more toxic than 2,4-D ester but insufficiently so to warrant definite conclusions in this regard. Tordon 101, a mixture of picloram and 2,4-D amine (20% active ingredient picloram, 80% 2,4-D amine), was slower acting but ultimately more effective than comparable amounts of the above ester sprays in top-killing of aspen poplar. It was both faster acting

and more effective than the esters on balsam poplar. Tordon 101 with added Atlox 210 acted faster and was much more effective than 2,4,5-T in the field and greenhouse trials on both aspen and balsam poplar.

Picloram potassium salt (Tordon 22K) was distinctly superior in visible toxicity in all treatments involving cuttings, foliage of plants in the field and foliage and roots of greenhouse plants. Added surfactant Atlox 210 greatly increased the phytotoxicity, in some cases by up to ten times as much as from picloram alone. Longer term studies of the economic feasibility of use of this herbicide-surfactant combination for brush control therefore deserve attention.

ACKNOWLEDGMENTS

The writer is indebted to Professor Wm. G. Corns for his encouragement and his constant guidance during the investigation and the subsequent preparation of this manuscript. Thanks are also extended to Mr. R. J. Schraa for the preparation of photographs and to Mr. L. G. Noel for his technical assistance with some of the field work.

Likewise it is a pleasure to acknowledge the use of equipment and facilities of the Department of Plant Science. This research was also made possible by financial assistance from the National Research Council of Canada.

Acknowledgment is made to the Dow Chemical Co. for supplies of experimental chemicals and to Atlas Chemical Industries, Brantford, Ontario, for supplying experimental quantities of Atlox 209 and 210.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

Much of the remaining potential agricultural land in northern parts of the Canadian provinces is covered by boreal forest which in many areas is mainly aspen and balsam poplar (*Populus tremuloides* Michx., *P. balsamifera* L.). These species pose a major problem of "brush control" also encountered, for example, in some of the livestock range regions in the Alberta foothills grasslands where conditions conducive to increased invasion of woody growth have occurred during recent decades. Such conditions include more favorable moisture supply, reduction in occurrence of fire, and in some cases, overgrazing. Agriculturists concerned about the growing need for more abundant food supplies recognize the great importance of achieving sound methods of efficient brush control, associated with other means for proper land management.

The systemic herbicides 2,4-D and 2,4,5-T have been used for many years with varying success in programs for control or eradication of poplar growth (8, 15, 34). One of the major disadvantages of the use of such herbicides, however, has been associated with their frequently inadequate penetration and translocation. Resultant incomplete killing of the tops and underground parts often permits extensive regrowth, particularly from suckers of lateral roots.

It is therefore of interest to attempt to find better formulations of herbicides to minimize the necessity for repeated treatments for satisfactory results. The present study was undertaken to compare the toxic effects on aspen and balsam poplar of some "brush killer" preparations including 2,4-D, 2,4,5-T and the more recently available picloram, trade name "Tordon", with and without additional surfactants in the herbi-

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

cide solutions. Balsam poplar was emphasized because, unlike aspen poplar, it has the ability to root from stem cuttings. This characteristic allowed for broader scope of the experiments.

LITERATURE REVIEW

Distribution and growth of poplars

The poplars are widely distributed in temperate regions of the northern hemisphere. About 35 species are recognized, 8 of which are native to Canada but 2 species are very widely known and distributed throughout Canada, namely aspen and balsam poplar (3, 31). Aspen poplar is in great abundance in the central to northern Canadian prairie region and is the principal species of bluffs in parkland areas. Since prairie fires (5) have been brought under control, this species is becoming more plentiful around sloughs and in low areas, even in the formerly treeless sections. Balsam poplar is common near water and in wet ground throughout the prairie area (31). It is quite widely distributed in other forest habitats as well, but is not as abundant as aspen poplar.

These trees in Alberta (5), reproduce most successfully by means of sucker shoots. Although large quantities of viable seed are produced each year by the female trees, seedlings, owing to unfavorable environmental conditions, rarely become established.

Brush control

There have been several field studies of a general nature dealing mainly with current seasonal effects of applications of herbicides (4, 9, 15, 21, 28, 34, 36, 37, 38) to stands of undesirable woody plants including aspen and balsam poplar (15, 34, 37, 38). There is, however, no information dealing with comparisons of such herbicides under closely comparable conditions to indicate clearly the differential responses of the two species to various herbicides in a given year or the beneficial

effects, if any, of adjuvants to the spray solution. Moreover there is a dearth of precise information about differential responses exhibited by the regrowth during the year after the chemical treatments.

Some interesting results from tree injection were obtained in an experiment with balsam poplar begun in 1962 by Corns and Schraa (8). The herbicides compared were an ester of 2,4-D, two formulations of water solubilized 2,4-D acid, an oil soluble, water emulsifiable 2,4-D amine (dacamine), a lithium salt of 2,4-D, and an ester formulation of 2,4,5-TP (silvex). In June of the year after treatment, they found that all of the 2,4-D dacamine and lithium-salt-treated-trees were leafless and 85% of the 2,4-D acid treated trees likewise were bare. Trees injected with ester formulations were not appreciably affected. Another year later in 1964, the data for survival of the trees in the various groups were: 2,4-D ester 60%, silvex ester 100%, 2,4-D acid, 2,4-D lithium salt, and 2,4-D dacamine no survivors. Moreover there was no regrowth from stumps of representative groups of trees cut during the previous year. With regard to the possible practical applications of this work, they concluded that suitably prepared penetrating formulations of the oil soluble, water emulsifiable amines might be more mobile and hence more effective than 2,4-D esters for basal spray treatments for killing trees. Corns (7) has also observed that balsam poplar appears to be more resistant to 2,4-D esters than is the aspen poplar. Consequently, related chemicals and formulations effective for control of balsam poplar might be expected to be at least equally effective against aspen poplar.

<u>Picloram herbicide</u>

In 1963, picloram (4-amino-3,5,6-trichloropicolinic acid) was

introduced as a potential herbicide (19). Picloram is a highly active, systemic compound, very soluble in water. When applied to the leaves and stems of woody plants in the conventional manner it produces growth responses similar to those from 2,4-D and 2,4,5-T (37). Initial reactions of the plants include curling of the leaves and twisting of new growth (1, 37). The main stems on some species also have a flattened appearance near the apex (1).

Picloram has shown considerable promise for the control of many woody plant species as well as herbaceous perennial weeds, by conventional foliage sprays (13, 17, 20, 34, 37). Preliminary data indicated that this herbicide was more effective on broadleaved than grass plants (19), and that it had considerable potential for rangeland use (1, 17).

Heikes (20) reported that generally one application of picloram at 2 lb/A was sufficient for complete control of several deep-rooted perennial weeds. The herbicide is highly active when applied to foliage (1, 4, 17, 19, 22, 34, 37), is translocated well (19, 22, 27) and has been very effective when leached into the root zone (18, 19, 38), because of its persistence in soil and susceptibility to leaching (19). Goring et al. (18) reported that the half-life for picloram in the soil was from 1 to 13 months.

Exploratory testing with this herbicide by Dow Chem. Co. research workers on a wide range of woody plants growing in plots and in a woody plant nursery revealed that this compound was active at low concentrations on many species (10, 13, 17, 34, 36, 37, 38). Watson and Wiltse (37) conducted a test in Michigan which showed that picloram at 0.5 lb/100 gal to wet the foliage gave complete top-kill without resprouting of many

woody species including some poplar species. Experiments conducted in Mississippi (37) indicated that picloram at 1 lb/100 gal was more effective than 2,4,5-T and 2,4-D at 4 lb/100 gal on a number of woody plants. Moreover, it was found that several woody plants that have been a problem to control on utility rights-of-way because they are prolific root sprouters have been susceptible to sprays with picloram. Some workers indicated that picloram is as much as four times as effective as 2,4-D and 2,4,5-T on several brushy species (13, 17, 36, 37). Schwartzbeck and Wiltse (34) showed that aspen poplar sprayed to wet the foliage was completely killed with picloram at 0.4 lb/100 gal while 2,4,5-T at 4lb/100 gal produced a 90% kill only.

Surfactants used in weed control

Surfactants may be defined as substances which are capable of altering the energy relationships at surfaces or interfaces, thereby reducing surface or interfacial tension (14). An increasing number of surfactants has found application in herbicides for weed control in recent years. While the primary purpose of a surfactant added to a herbicide is to promote wetting and coverage of the leaf surfaces (12, 14, 25, 33), the unique hydrophilic-lipophilic properties of these additives (2) have suggested that they may be capable of more than this one function. They may regulate spray retention (32, 33), herbicide penetration (12, 14, 33), or plant cuticle solubilization; they may act as herbicide co-solvents (2, 12), chemical reactants, or complexants; they may aid in water retention as humectants (12) or hygroscopic agents; they may reduce volatility.

The concentration of surfactant in herbicide preparations is

important with regard to potential reactivity. Jansen et al. (25) reported that phytotoxicity was most pronounced when the surfactant concentration was 1.0% or more. They found that progressive enhancement of herbicidal activity was obtained with logarithmic increases in concentration of some surfactants. Generally, spray adjuvants are normally added to a dilute spray at the rate of 0.5 - 1% (2, 4, 16), a much higher concentration than provided by the surface active agent from the aliquot of the commercial emulsifiable concentrate preparation used in preparation of spray volumes.

Two of the top selections of surfactants by Atlas Chemical Ind., Inc. (16), Atlox 209 and 210, have become available for experimental use. These surfactants at 0.25 to 1.0% concentrations (16) have increased the activity of atrazine, diuron, prometryne, paraquat, 2,4-D and some other herbicides. Gakenheimer (16) also pointed out that the activity of diuron applied at 1 lb/A was enhanced more by 1% Atlox 210 than by 1% Atlox 209. He thought that this was probably the result of the lower hydrophilic-lipophilic balance (HLB)-9, of the Atlox 210 as compared to the higher HLB-15, of Atlox 209. We have found no references to use of these substances in brush control treatments.

Application methods

In common practice "low volume" spraying uses only 10 gallons or less liquid carrier per acre. Under such conditions best results have usually been obtained following treatment with 2,4-D ester formulations on early season fully leafed growth (15, 21, 28). The advantage of the oily emulsions of 2,4-D esters, particularly when spray volume is small, may be associated with their superior ability to spread over, mix with,

and penetrate wax or cuticle leaf surfaces (12, 14, 21, 33). At the same time this behavior largely avoids the danger of loss by run-off if rain occurs soon after spraying. Nevertheless, there is room for improvement. Distinct benefits could come from more effective herbicidal formulations and techniques of application that would result in greater movement of the herbicide to the roots of poplars. This would prevent or reduce the regrowth following the initial chemical treatment.

Foliage sprays may be applied as high volume, low concentration or low volume, high concentration. The former are usually more efficacious but the latter are easier and cheaper to apply (21).

Recommendations for applications of herbicides to the leafless trees during the dormant season or localized treatments of the basal bark regions have been worked out over the years (21, 28). There is good evidence to indicate that these more expensive treatments are often more effective than foliage spray, probably due to the fact that there is usually complete wetting of the root collar zone. This technique is particularly useful for areas of scattered weed trees.

Tree injection techniques (8, 36) have in many cases been quite successful but are not feasible for most agricultural purposes because of the cost and labor involved. From a research standpoint however they provide useful information about the movement and toxicity of various herbicides and their different formulations within trees.

EXPERIMENTAL

The herbicides included in this work were derivatives of picloram (4-amino-3,5,6-trichloropicolinic acid), 2,4-D (2,4-dichlorophenoxyacetic acid), 2,4,5-T (2,4,5-trichlorophenoxyacetic acid), and silvex (2-(2,4,5-trichlorophenoxy) propionic acid). Formulations of picloram and 2,4-D used were potassium salt of picloram (trade name Tordon 22K), a mixture of picloram 20% and 2,4-D 80% acid equivalent in amine form (Tordon 101), 2,4-D solubilized acid (hereafter called 2,4-D acid), 2,4-D dimethyl amine, 2,4-D ethyl ester, 2,4-D emulsamine, and 2,4-D salt. The formulations of 2,4,5-T and silvex were esters, isooctyl ester of 2,4,5-T and propylene glycol butyl esters of silvex. The sources of the herbicides are listed in Appendix Table 1.

References to amounts of herbicide application as active ingredient in the carrier are in parts per million (ppm) or pounds per acre (lb/A). Total volume of liquid applied is expressed in Imperial gallons per acre (gal/A). Similarly reference to spraying pressure is abbreviated from pounds per square inch to psi.

Detailed description of experiments is divided into three parts concerning laboratory work with balsam poplar cuttings, treatment of young trees in greenhouse, and branch dipping and foliage spray treatments in the field.

I. Rooting responses of balsam poplar cuttings treated with herbicides in the laboratory

1. Herbicide absorbed by bases of cuttings

A. Materials and methods

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

1. [illegible]

2. [illegible]

Most of the dormant poplar shoots were collected in the vicinity of Edmonton in the fall and were stored in a coldroom at about 5°C. The shoots used were one to two years old, about 0.5 - 1.0 cm in diameter, with quite uniform buds. Experiments with this material were conducted in the spring of 1965 and of 1966. After several months of dormancy of the branch material, the development of roots following different treatments could be studied readily.

Herbicides used in this experiment were picloram K salt, 2,4-D acid, 2,4-D emulsamine, 2,4-D ester, and 2,4,5-T. For each chemical three concentrations (5, 10 and 20 ppm) were used. Household preserving jars about 10 inches tall and 4 inches in diameter with wide mouth and metal screw cap were used as containers for the cuttings and the different chemical preparations. Cuttings approximately 7 inches long and each having 3 or 4 buds were used for each of 3 replicates per treatment. Seventy ml of aqueous chemical preparation were added to each jar to keep the bases of the cuttings wet for about 1 cm. Controls contained distilled water. For ventilation, lids of the jars were perforated by 2 holes about 0.4 cm in diameter.

The jars were kept in the dark at 25°C prior to taking records of results two weeks after commencement of the tests.

B. Results and discussion

Data recorded two weeks after treatment show in Fig. 1, the number of roots, and in Fig. 2, the extent of callus formation on the top of the cuttings.

Fig. 1 shows that different formulations of herbicides varied in their effects on root development. Ester did not inhibit root development

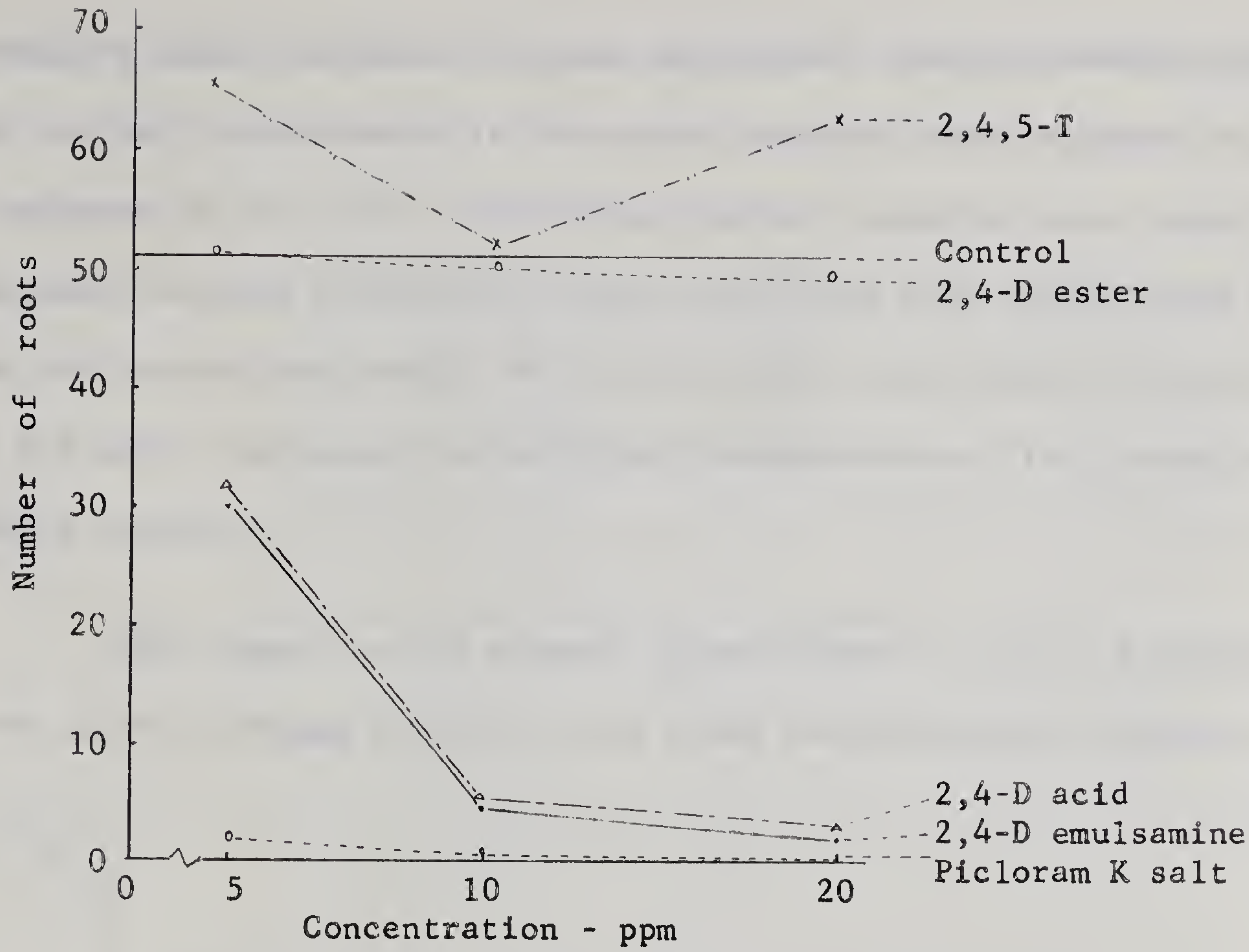


Fig. 1 Rooting responses of balsam poplar to picloram and some phenoxy herbicides (means for 3 replicates).

but it was decreased substantially by 2,4-D acid and emulsamine and it was also greatly inhibited by picloram K salt. All the concentrations of picloram were very effective in inhibiting lateral root development along the length of the cuttings. It is known that picloram has high penetrating ability and is more toxic than certain other herbicides (1, 4, 13, 17, 20, 34, 36, 37). Effective translocation and toxicity of picloram is also indicated by these results concerning root development of balsam poplar cuttings. At the highest concentration, 20 ppm, 2,4-D acid and 2,4-D emulsamine were nearly as effective as was picloram at its lowest concentration.

On the other hand, 2,4-D ester and 2,4,5-T ester showed very little effect in preventing root development indicating that there was a lack of

adequate upward movement of these herbicides. Results showing that ester is not well translocated in the plant body have been reported in other instances (8, 21, 27). Penetration however, seems to occur quite readily. In most cuttings treated with ester there were very obvious bark splits on the treated part only. On the other hand, bark splits of cuttings in 2,4-D acid, emulsamine and picloram treatments were distributed along the whole cutting.

With regard to the effects of herbicides on callus formation at the tip of cuttings (Fig. 2) it is clear that different chemicals also

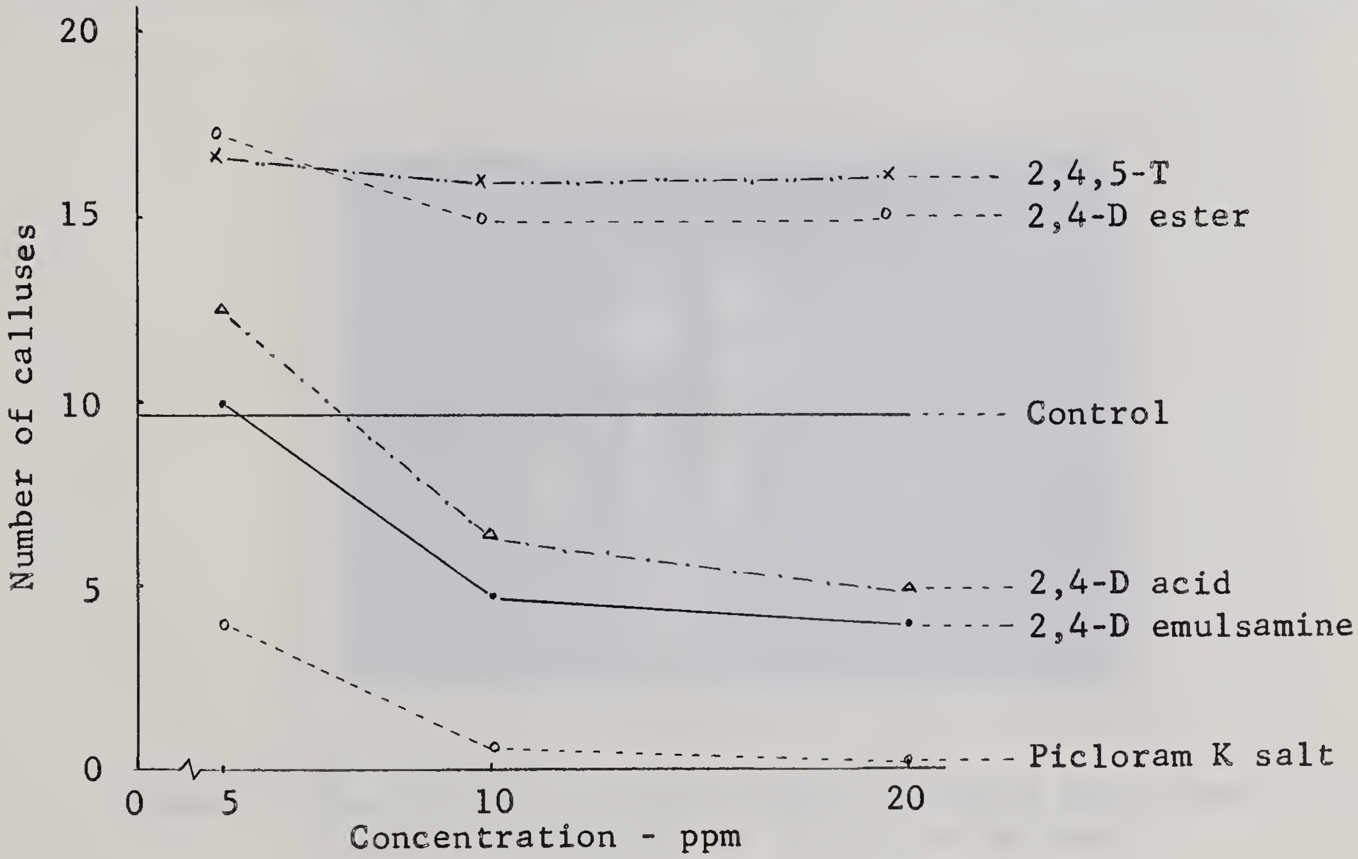
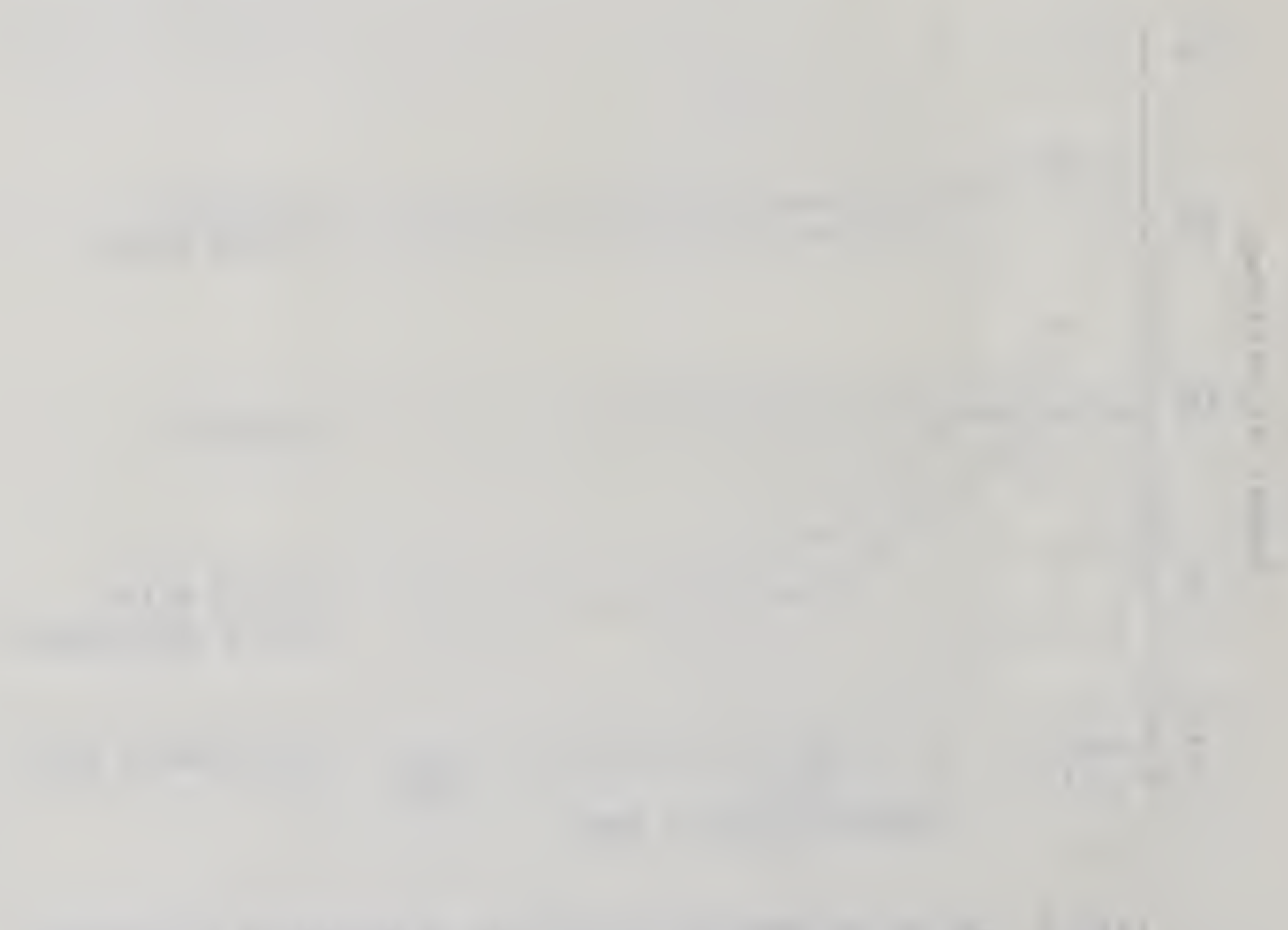


Fig. 2 Callus formation at the tip of cuttings following treatments with herbicides. Eighteen cuttings used in each treatment. (Total for 3 replicates).

had different effects on the callus formation. Picloram K salt caused strongest inhibition of callus formation, while 2,4-D acid and 2,4-D emulsamine caused only moderate inhibition. Ester formulations of 2,4-D



and 2,4,5-T, if anything, apparently favored callus formation at the tips and on the immersed part. However the untreated lateral portion of ester treated cuttings was not affected even when concentration of 2,4,5-T was raised to 80 ppm in a later experiment. This would suggest that translocation of amounts of such esters insufficient to inhibit lateral root development may nevertheless influence development of callus tissue at the tip. Another possibility is that tip callus formation is stimulated by ester vapor volatilized from the liquid within the jars.

The callus was spongy tissue which was white at first then gradually became brown (see Fig. 3). In picloram, 2,4-D acid, and 2,4-D emulsamine

Fig. 3 Tip callus of balsam poplar cuttings after two weeks of treatment in 2,4,5-T at 20 ppm.

treatments there were splits along the length of the cuttings and callus tissue surrounding the splits was also found. This callus was soft and loose similar to the tip callus and gradually expanded after rupture of the bark (Fig. 4). In an anatomical study of callus development by Cormack (6) callus formation was characterized by the swelling and rupturing of the periderm in localized areas which coincided with the expansion

of the terminal and uppermost lateral buds. In the present work the bark callus was mostly formed at the location where adventitious roots develop.

Fig. 4 Bark split and callus formation of balsam poplar cuttings after 2 weeks of treatment in 5 ppm picloram solution.

When the cuttings were grown in distilled water, small, nipple-shaped callus masses were formed with adventitious roots. When roots grew, the small callus mass stopped swelling. However, as indicated earlier the cuttings treated in certain chemical solutions had more serious splitting of bark and more conspicuous callus masses along the cutting.

2. Herbicides applied by surface treatments of cuttings

A. Materials and methods

The purpose of this experiment was to evaluate the effects of predipping balsam poplar cuttings for different lengths of time in various concentrations of herbicides as indicated later.

The cuttings used for these treatments were similar to those used in the foregoing experiment. There were 6 cuttings and three replicates for each treatment. The groups of cuttings for the various treatments were dipped to allow comparisons of (a) complete exposure to the herbicides, (b) exposure of upper half of the cuttings only, and (c) exposure of lower half of the cuttings only. Following the dipping procedures, all the treated cuttings were transferred to glass jars like those used in the foregoing experiment. All jars contained only distilled water to cover the basal parts of the cuttings during their incubation period in the dark cabinet.

B. Results and discussion

(a) Rooting response of balsam poplar cuttings whose lower half was dipped in 2,4-D solution for various periods of time before incubation in the dark: the mean results of two experiments (May 1965, June 1966) are shown in Fig. 5. It is noted that the dipping time was inversely correlated with the number of roots developed on the cutting and that near maximum suppression of root growth was achieved by dipping exposures of 3 minutes duration. On the basis of similar results from other preliminary experiments a standard dipping time of three minutes was used in more extensive studies whose results follow.

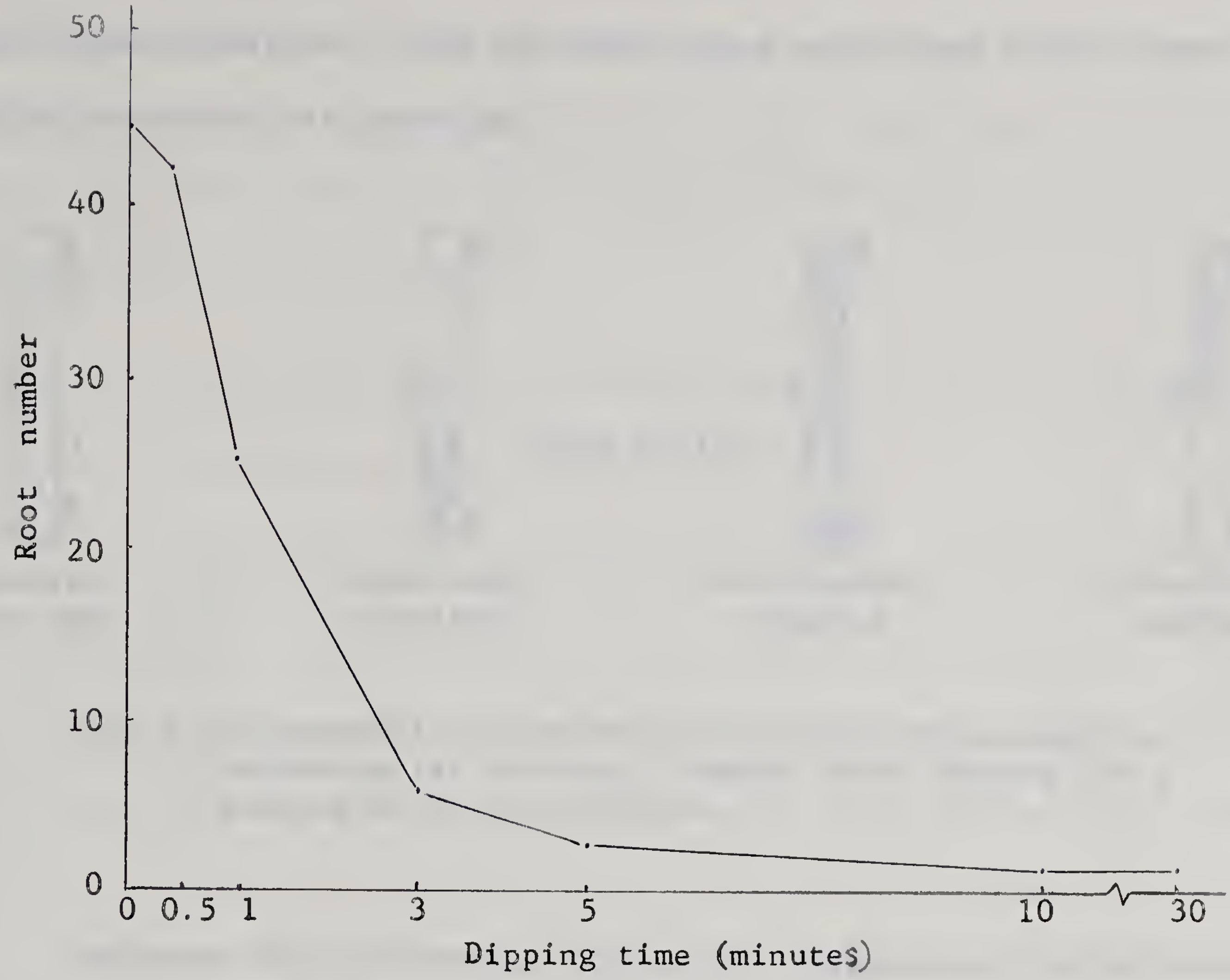


Fig. 5 Root development on balsam poplar cuttings 2 weeks after dipping for various lengths of time in 100 ppm 2,4-D acid.

(b) Rooting response of balsam poplar cuttings whose entire length or upper or lower half, was dipped in picloram for three minutes before incubation in the dark.

Results with 20 ppm picloram were chosen for illustrative purposes here because this dosage produced near maximum effect and was therefore comparable to the 100 ppm 2,4-D treatments. The accompanying sketches (Fig. 6) illustrate the results. Untreated cuttings produced abundant roots. Treated upper or lower parts of cuttings temporarily had a few roots. These roots were short, abnormal, and later died. The bark of treated parts was swollen and had many splits. These were associated

with callus formation. When the whole piece was dipped results were similar to those just described.

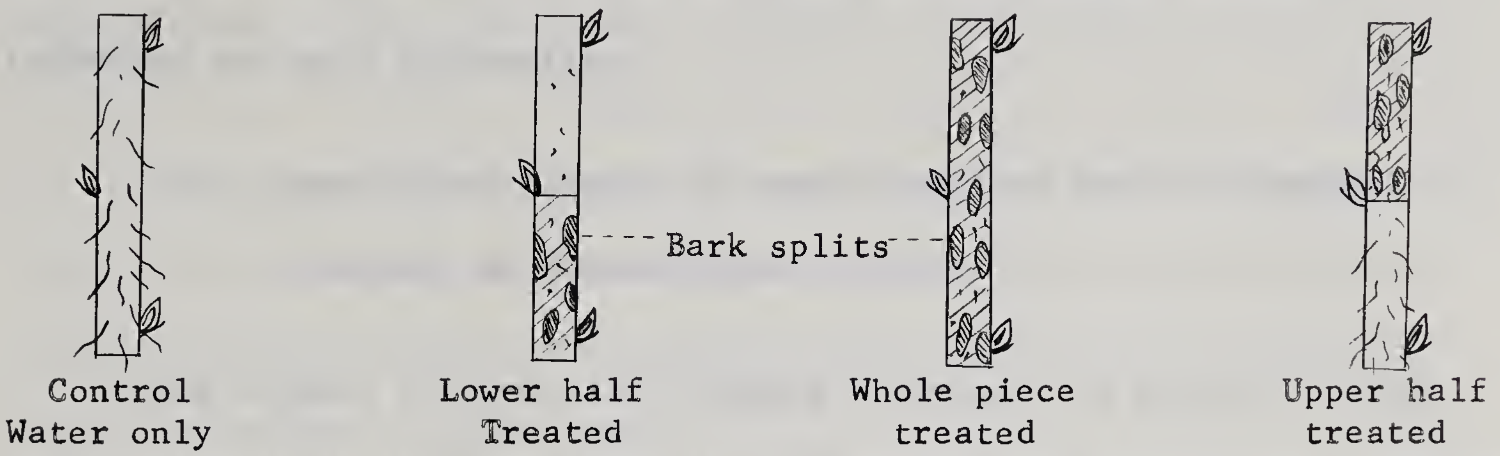


Fig. 6 Diagrammatic representation of root development on balsam poplar cuttings 2 weeks after dipping for 3 minutes in 20 ppm picloram.

The upper half of cuttings whose lower region was treated developed only a few small roots much less numerous and vigorous than on the control material.

After dipping the upper half of the cutting, roots which developed on the lower half were very strong and were similar to the roots from the untreated controls. From these results it can be seen that the chemicals were very effective in inhibiting root growth from treated parts but there was very little or no downward movement in these cuttings. On the other hand in this experiment, it has been shown that after dipping the lower half of the cuttings there was upward translocation of solution which influenced root growth throughout the cutting. In this connection interesting differences among the various herbicides will be summarized later. Since greenhouse and field experiments also to be described later showed that there was some downward movement of picloram in growing poplars the results of use of isolated cuttings with treatment of their upper portion

are evidently misleading. In subsequent experiments involving comparisons of dipping treatments of balsam poplar cuttings, application of the herbicide to the lower portion of the cuttings was emphasized because this technique was more instructive.

(c) Comparative effects of some herbicides used in dipping treatment of balsam poplar cuttings

The effects of herbicidal dipping treatments on poplar cuttings in experiments in 1965 confirmed in 1966 varied with herbicides. Comparisons were based on number and condition of roots and upon other visual evidence of toxicity induced by the herbicides as summarized in Table 1.

Table 1. The effects of picloram and phenoxy herbicides on balsam poplar cuttings after dipping treatment. Data used are means of three replicates recorded two weeks after herbicidal treatment.

	10 ppm		20 ppm		40 ppm	
Herbicide	Root no.	Injury*	Root no.	Injury	Root no.	Injury
Picloram	31	5.0	18	6.0	8	8.3
Tordon 101	55	1.3	41	3.0	30	5.7

	40 ppm		80 ppm		160 ppm	
Herbicide	Root no.	Injury	Root no.	Injury	Root no.	Injury
2,4-D amine	49	3.0	22	5.0	10	8.7
2,4-D ester	43	2.7	24	4.0	10	8.3
2,4,5-T	62	1.3	60	1.7	36	2.7
Control	61					

* Injury scale: 0 - no effect; 10 - complete kill.

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]				

[illegible]

These herbicides may be discussed in classes.

(1) Picloram. Picloram K salt and Tordon 101 are included in this category. These herbicides are highly water soluble. Picloram K salt was most effective in inhibition of lateral root growth. Tordon 101 was less effective in comparison with picloram, but it was more effective than 2,4-D amine (e.g. compare 40 ppm dosages). This type of result is reasonable because Tordon 101 contains 20% picloram and the remaining active ingredient is 2,4-D amine.

(2) 2,4-D acid and emulsamine. Both 2,4-D acid and emulsamine were emulsified formulations. One experiment conducted in May 1965 was designed to compare the effects of 2,4-D acid and emulsamine with picloram. The results listed in Table 2 show that 2,4-D acid and emulsamine were moderately effective but were less effective than picloram. Obviously 2,4-D acid and emulsamine were about equally effective.

Table 2. Effects of picloram and 2,4-D on cuttings of balsam poplar after dipping treatment. Data used are means of three replicates recorded two weeks after dipping.

Herbicide	Root number			
	10 ppm	50 ppm	100 ppm	control
Picloram K salt	33	12	0	46
2,4-D acid	41	34	10	
2,4-D emulsamine	44	31	2	

(3) Amine: 2,4-D amine is representative of this type which is highly water soluble. The effect of amine on root numbers seems less pronounced

than that of formulations in the previous two categories but in some respects, effect of translocation of amine in cuttings was apparently more pronounced than with other formulations of 2,4-D and 2,4,5-T, since the amine treated cuttings were uniformly split along the whole piece.

(4) Ester: Esters of 2,4-D and 2,4,5-T belonged to the group emulsified with oil and water. Since ester has rapid penetration and poor translocation in plant tissues (27), most cuttings treated with the ester showed accumulated response in the treated base of cuttings typified by serious bark splitting and swollen callus tissue there. 2,4-D ester only moderately inhibited root growth and formed conspicuous tip callus. This may have been affected by vapor of ester, that is to say an effect exterior to the cuttings within their container. Similarly root development was very little inhibited by 2,4,5-T ester. Though the roots were weak and slender, they grew quite well from cuttings treated even at very high concentrations (160 ppm). Apparently, 2,4,5-T like 2,4-D ester had very little effect in inhibition of root growth owing to its poor translocation. Its perhaps slightly less pronounced effect on root development as compared with 2,4-D ester may have been related to the lower volatility of the "low volatile" 2,4,5-T formulation.

3. General conclusions

The root development of balsam poplar cuttings treated with herbicides has shown various responses. In the treatments involving absorption of herbicide continuously available from liquid at the base of cuttings there was most inhibition of subsequent root growth. In the dipping treatments there was no evidence of downward translocation of herbicides in detached cuttings. There was upward movement from treated lower parts.

The treatment of the lower half of cuttings prior to their incubation period was therefore more effective than treatments of the upper half in revealing differences in toxicity among different herbicides, formulations, and dosages.

Of the herbicides used in these experiments picloram K salt was the most readily translocated upward and the most inhibitory to root development; while acid, emulsamine and amine formulations of 2,4-D were more effective than ester formulations of 2,4-D and 2,4,5-T in this connection. Ester formulation had almost no effect on root development as a result of herbicide translocation. The apparently somewhat stimulatory effect of ester on callus formation may have been due to movement internally of minute traces of ester to the upper tips of the cuttings or externally by volatilization.

II. Responses of young plants to foliage and stem treatments with herbicides in the greenhouse

1. General preparation of materials

Experiments were conducted in a greenhouse with controlled minimum temperature of 18.5°C. During the winter the temperature was approximately constant at this level. However, during the summer the temperature was often in excess of 35°C. Supplementary lighting was given during the winter to keep the day length at 16 hours by using 200 watt incandescent bulbs. The bulbs were placed two feet apart and three feet above the pots, giving a light intensity of approximately 500 ft-C. at foliage level.

All the plants were grown in plastic pots. The size of the pots

varied with the type of experiment. Most young trees from cuttings were grown in 6 and 8 inch pots containing a standard soil mixture of three parts of Edmonton black loam soil to one part of sand and one part of peat. Watering varied with weather. In summer, water was applied to the soil surface once a day to keep the pots in moist condition.

The preparation of the cuttings used in the experiments of this section was the same as the procedure of previous laboratory experiments. Usually 6 to 8 inch lengths of one to two-year old cuttings were used for planting in pots. Two cuttings were planted in each pot and a month later healthy saplings were selected for the experiments. At this time, fertilizer, ammonium phosphate (analysis 16-20-0), was applied with the water. The quantity used was calculated to supply the amount equivalent to a total of approximately 500 lb/A. During the growth period the plants were fumigated to prevent insect and disease damages. Three to four months later, when the saplings were about 18 inches in height with 6 to 8 leaves on the shoot, the young plants were used for treatments.

2. Foliage spray treatments

A. Materials and methods

In most of the experiments, treatment solutions were applied to the plants by foliar spray. Different formulations of 2,4-D, 2,4,5-T, and picloram were applied to compare their effects on young trees. However, in some cases surfactants were added to facilitate the penetration and translocation of the herbicides (2, 12, 14, 24, 25, 32, 33). The details of these treatments will be described later.

In the first experiment the young trees of balsam poplar were

grown for three months in 8 inch plastic pots. Each pot had only one sapling which was approximately 18 inches in height and with 5 - 6 leaves. Tests with two rates (5000, 10000 ppm) each with four replicates for every treatment were performed to compare the effects of acid, amine, emulsamine and ester formulations of 2,4-D, ester formulation of 2,4,5-T, and picloram K salt. A volume of 10 ml of herbicidal solution was sprayed from a small squeeze bulb atomizer, on 3 square feet area. This volume was approximately equivalent to 30 gal/A. The sprayed area was bounded by a plastic frame 3' x 1' x 3' high. A randomized block design for each herbicidal treatment was used. The visual effects were observed and after 6 weeks, quantitative data were obtained by calculating % moisture by comparing the fresh weight with oven dry weight of treated shoots and leaves. The expectation was that the greater the effect of the herbicide the smaller would be the moisture content of the treated plant.

In a second experiment only the upper part of plants was treated in order to permit observation of visual effects of downward translocation of the herbicides on the untreated lower portion of the above ground vegetation. The shoots were marked by plastic ribbons 10 inches from the tip. Paper towels were fastened in place to shield the lower half of the shoots during the spray operation. Tordon 101, amine and ester formulations of 2,4-D, and 2,4,5-T were applied at 1000 and 2000 ppm by atomizer to give an equivalent of 30 gal/A, on three replicates. After 1, 2, and 4 weeks of treatment the results were recorded by visual ratings of foliage injury.

In the third experiment a cabinet sprayer was used to apply the treatment solutions. This consisted of a single nozzle boom which was

mechanically propelled along the length of the cabinet. At 40 psi and with a type 650067 "Tee Jet" nozzle it delivered 16.5 gal/A for one passage down the length of the cabinet with nozzle height approximately 18 inches above the plants. Two passes were used to apply 33 gal/A, comparable to the amount used in the previous experiments. Three rates, 1000, 2000, and 3000 ppm of Tordon 101 and picloram, 2000, 3000, and 4000 ppm of amine, acid, and ester formulations of 2,4-D and 2,4,5-T, were used on four replicates. Results obtained from visual ratings of speed and extent of foliage injury were compared using Duncan's new multiple-range test (35).

B. Results and discussion

Visible effects of herbicidal application could be seen after two days in many cases. Leaf bending and wilting response to ester formulations occurred sooner than for other formulations probably owing to the more rapid penetration (21, 27). After 5 days of treatment, the effects of picloram caught up to and gradually surpassed the effect of the other herbicides. There was no appreciable difference between results from 2,4-D and 2,4,5-T esters. With these esters, in the first experiment, only the upper young foliage was killed and the lower part and root system survived even the rather large dosage of 10000 ppm. The emulsamine and acid of 2,4-D showed more serious injury on foliage and high concentrations almost completely killed the young trees. Amine of 2,4-D showed slower initial injury to vegetation but after approximately three weeks this treatment, appeared to be more effective than esters. All herbicides even at 10000 ppm still had not completely killed the young trees. Picloram however, at the lower rate killed the entire foliage.

[illegible]

[illegible]

[illegible]

In this first experiment the assessment of extent of killing of the trees was made six weeks after treatment. The treated plants were dug up to examine the root system. It showed that the roots of picloram treated plants were completely killed and those from 2,4-D amine treatments were seriously injured. Root systems of ester treated plants remained similar to untreated plants. From these results it seemed obvious that picloram and 2,4-D amine were more readily translocated in the plant body. This is in line with results with various other species reported in previous publications (13, 17, 20, 21, 27, 29).

The water content in plants from the various treatments is shown in Table 3. As might be expected significant differences, when they

Table 3. Percentage of water content in balsam poplar after herbicide treatments. Mean of two replicates six weeks after spraying.

	5000 ppm			10000 ppm		
Treatment	Leaf plus stem	Stem	Leaf	Leaf plus stem	Stem	Leaf
Picloram K salt	38.01*	50.85	8.07*	35.79**	44.74	6.31**
2,4-D acid	56.74	59.02	27.23*	44.58**	46.45	13.03**
2,4-D emulsamine	48.78*	51.56	42.39	50.56**	51.46	19.96**
2,4-D amine	54.60	51.94	51.94	51.23*	57.49	38.03**
2,4-D ester	58.99	52.65	51.25	51.71*	50.07	45.47*
2,4,5-T	60.30	52.26	53.91	58.44	53.44	48.15*
Control	65.81	53.55	67.53	65.81	53.55	67.53
LSD 5%*	12.67		25.40	9.80		18.50
1%**				14.85		28.03

occur, are attributable to effects of the herbicide on the leafy portion of the plants rather than to differences among woody stem materials. In line with visual observations recorded earlier 2,4-D acid and emulsamine were less effective than picloram but they were clearly better than other treatments. Despite their more rapid initial injury to leaves, ester treatments were ultimately the least effective with regard to gross leaf damage.

In the second experiment involving treatment of only the upper stem parts with lower concentrations of herbicides the results again showed that ester formulation caused the most readily visible effects during the first few days after treatment of the plants. The effects of ester and Tordon 101 at the low rate appeared quite similar (Table 4). Actually, it was too low a concentration for complete killing of foliage. However, the main purpose of this treatment was comparison of the visible

Table 4. The responses of young balsam poplar to Tordon 101 and phenoxy herbicides applied on the upper foliage in the greenhouse

	Injury rating*					
	1000 ppm			2000 ppm		
Herbicide	1 wk	2 wk	4 wk	1 wk	2 wk	4 wk
Tordon 101	2.7	5.3	7.7	6.0	9.3	9.7
2,4-D amine	1.7	2.8	4.3	2.3	4.8	6.7
2,4-D ester	2.3	3.3	5.0	3.0	6.7	8.3
2,4,5-T	2.3	5.5	7.7	3.5	6.0	7.7

* Injury rate: 0 - no effect; 10 - complete kill. Data used are means of three replicates.

effects of downward movement of the herbicides; hence use of lower concentration is more likely to permit detection of differences which might be masked by heavier dosages. Ester formulations of 2,4-D and 2,4,5-T did not show effects on lower untreated foliage; after four weeks of treatment lateral branches emerged and grew well below regions where the main shoot was seriously injured. The amine of 2,4-D in some plants showed effects of greater downward translocation than ester formulation. The symptoms of injury at the top however were not usually as severe as after treatment with ester (Table 4). Tordon 101 being a mixture of picloram and 2,4-D amines was in most treatments more effective than the other herbicides except picloram K salt. At the time of final observations a much greater number of the Tordon 101 treated plants had dead leaves and bark splitting in the lower untreated region than did 2,4-D amine treated saplings. In addition the tip of treated shoot always stopped growth and showed extreme swelling (1) illustrated in Fig. 7.

Fig. 7 Injury to the apical region of balsam poplar four weeks after spraying with Tordon 101 at 1000 ppm.

In the third experiment, involving the herbicides and amounts applied from the cabinet sprayer, picloram formulations and 2,4-D acid

were more effective than other formulations of phenoxy herbicides (Table 5). Differences between various treatments were most distinct 3 weeks after their application. The effects of picloram formulations and 2,4-D acid were uniform throughout the foliage and stem; 2,4-D amine showed effects mainly near the tip and on the young portion of the stem. Ester generally killed the young tip with young leaves only.

3. Enhancement of herbicidal activity by added surfactants

There are several publications concerning the use of surfactants in formulating agricultural sprays. Only recently, however, has interest been stimulated regarding the use of surfactants to increase the efficacy of herbicides (23, 24, 25, 32). In the interests of safe use of surfactants on food crops, such experimental work has been largely restricted to trials with those wetting agents recognized widely as being harmless in foods. Two products identified as Atlox 209 and 210 manufactured by Atlas Chemical Industries, Inc. (16) are according to the manufacturers, in this category, being appropriately biodegradable (2) and possessing a suitable HLB (hydrophile-lipophile balance) to enable them to be useful spray adjuvants. Their physical properties are indicated in Table 6.

The studies reported herewith were undertaken to determine whether these compounds, hitherto evaluated primarily in connection with crop plants and considered by the manufacturers to be their two best products for the purpose, might be useful in improving the efficiency of brush control herbicide.

Table 5. Effects of foliage sprays of several herbicides on balsam poplar in the greenhouse

Herbicide (b)	Injury rating (a)															
	1000 ppm				2000 ppm				3000 ppm				4000 ppm			
	5 day	10	20	30	5	10	20 (c)	30 (c)	5	10 (c)	20 (c)	30 (c)	5	10	20 (c)	30 (c')
Picloram K salt	1.0	1.0	2.8	9.9	1.0	1.6	9.0^{a}	9.9^{a}	1.8	4.4^{a}	8.1^{a}	9.9^{a}				
Tordon 101	1.0	1.0	2.3	9.0	1.5	1.8	5.5^{bc}	9.9^{a}	2.4	4.3^{a}	8.8^{a}	9.9^{a}				
2,4-D acid					1.0	1.5	8.5^{ab}	9.9^{a}	1.0	1.8^{b}	9.0^{a}	9.9^{a}	1.0	2.5	9.0^{a}	9.9^{a}
2,4-D amine					1.0	1.0	1.8^{d}	4.8^{b}	1.0	1.3^{b}	3.5^{b}	7.0^{b}	1.0	1.3	3.5^{b}	7.5^{b}
2,4-D ester					1.4	1.5	2.3^{d}	5.3^{b}	2.0	2.3^{b}	4.0^{b}	7.8^{b}	2.0	2.5	4.5^{b}	8.5^{a}
2,4,5-T					1.0	1.0	3.0^{cd}	6.0^{b}	1.0	1.4^{b}	3.0^{b}	7.3^{b}	1.0	1.9	3.0^{b}	7.5^{b}

(a) Injury rate: 0 - no effect; 10 - complete kill. Data used are means of four replicates.

(b) Herbicide application rates based on 33 gpa spray volume.

(c) Figures within each column having the same letter designation are not significantly different at the 1% level and 5% level (c').

Table 6. Physical properties of Atlox 209 and 210 (16).

Physical property	Atlox 209	Atlox 210
Appearance at 77°F	Light amber liquid	Light amber liquid
Appearance at 0°F	Light amber liquid	Cloudy amber liquid
Specific gravity at 68°F	0.995	0.963
Viscosity (cps at 77°F)	50	30
HLB	15	9
Solubility in water	Soluble	Dispersible

A. Materials and methods

(a) Comparison of Atlox 209 and 210: During June and July of 1965, an experiment was conducted in the greenhouse to evaluate the effects of surfactants, herbicide, and surfactant-herbicide mixtures. Six treatments, Atlox 209 at 1%, Atlox 210 at 1%, 500 ppm of Tordon 101, Tordon 101 with 1% of Atlox 209, Tordon 101 with 1% of Atlox 210, and Tordon 101 with 1% of Atlox 209 and 210 mixture were used with foliage spray applications of 10 ml solution on 3 square feet surface area. The experimental design was a randomized one with three replications (pots) of each treatment using young trees of balsam poplar grown in 6 inch plastic pots in the greenhouse under conditions described previously. One and three weeks after treatment each pot was visually scored for the foliage injury.

(b) Concentration of surfactant: In the winter of 1965, spray application of five herbicides, picloram K salt, Tordon 101, amine and ester formulations of 2,4-D, and 2,4,5-T were used at 1000 ppm with

[illegible]

[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]

[illegible]

[illegible]

[illegible]

Atlox 210 at 0.25, 0.5, and 1% concentrations. The experiment was conducted using randomized block design and the results were recorded as ratings of injury from 0 to 10. In a second experiment only two herbicides, picloram K salt and Tordon 101 were used at a single rate, 500 ppm, with variation in concentration of Atlox 210 to try smaller amounts. The results from visual ratings as noted above were analysed statistically using Duncan's test (35).

(c) Effects of herbicides with surfactant on aspen and balsam poplar: In the previous experiment various concentrations of wetting agent and one concentration of several herbicides were used. In one of these additional experiments, spray application of several herbicides was used at different concentrations with Atlox 210 at a single rate on balsam poplar. These treatments details of which appear in tabular form later, were performed during both the summers of 1965 and 1966 and some of the results obtained from ratings of injury were compared using Duncan's statistical test.

Most materials of the previous experiments were young saplings of balsam poplar using previously dormant cuttings grown in plastic pots. Aspen poplar does not grow from shoot cuttings. For experiments with this species therefore young aspen poplar root 'suckers' were dug up from a native stand in the fall of 1965 and stored at 41^{o}F in a cold room for one month before transfer to the greenhouse. In a second experiment the young trees were dug up in May 1966 and transplanted to 8 inch plastic pots in the greenhouse. Identical treatments were arranged for both aspen and balsam poplar to compare the test herbicides sprayed on these tree species.

(d) Effect of surfactant with ester formulation of herbicides:

In practice, because of efficiency (21, 26, 27) and economy, ester formulations of 2,4-D and 2,4,5-T are commonly used in brush control operations (9, 15, 28). There are reports that surfactants enhance the herbicidal activity of salt or amine formulations of 2,4-D (23, 24, 25). However, little research with surfactants has been reported concerning esters. In this experiment ester formulations of 2,4-D and 2,4,5-T were used at different concentrations with 1% of Atlox 210. The ratings of toxicity were recorded two and four weeks after foliage treatment with the herbicides.

(e) Effect of surfactant with picloram and 2,4-D amine: In the summer of 1966, an experiment was designed to evaluate the effect of Atlox 210 with picloram and with 2,4-D amine on balsam poplar. Since these two herbicides are believed to be translocated more readily than certain others (19, 21, 26, 27) it was thought that such activity might be enhanced further by the presence of surfactant in the spray mixture. The cabinet sprayer was used to apply the treatment solutions. The solutions used were as follows:

Treatment	Picloram	2,4-D amine
Without surfactant	1000 ppm	1000 ppm
	2000	2000
	3000	3000
	4000	4000
	5000	5000
	6000	6000
With 1% v/v of Atlox 210	250	500
	500	1000
	1000	2000
		3000

B. Results and discussion

(a) Comparison of Atlox 209 and 210: Differences in phytotoxicity values for Tordon 101 at 500 ppm were attributed to differences between Atlox 209 and 210. After one and three weeks of treatment, the foliage injury was scored and is shown in Table 7. The results indicate that the

Table 7. Comparison of Atlox 209 and 210 with Tordon 101 showing their herbicidal effect on balsam poplars.

Treatment*	Injury rating** 1 wk	3 wk
Atlox 209	0	0
Atlox 210	0	0
Tordon 101	1.4	3.5
Tordon 101 + Atlox 209	3.2	6.5
Tordon 101 + Atlox 210	4.0	7.8
Tordon 101 + 209 + 210	3.5	7.0
Control	0	0

* Spray application based on approximately 30 gal/A spray volume. The concentration of surfactants was 1% v/v.

** Injury rate: 0 - no effect; 10 - complete kill. Data are means of three replicates.

additions of Atlox 209 and 210 increased the activity of Tordon 101. Surfactants without herbicide caused no injury. Therefore, enhancement of herbicidal activity was not due to the toxicity of surfactants. There is a possibility that it might be a synergistic effect (11) between surfactant and herbicide.

Observations on both dates revealed that Tordon 101 toxicity

to balsam poplar was increased by both surfactants, Atlox 210 promoting a greater increase than Atlox 209. The results on the second date showed that the effect of Tordon 101 with a mixture of 0.5% of Atlox 209 and 0.5% of Atlox 210 was between the effects of Tordon 101 with 1% of Atlox 210 and with 1% of Atlox 209. Because of this finding that addition of Atlox 210 was associated with more effective herbicidal action than was the case with Atlox 209 on this woody species, Atlox 210 was used exclusively in all later experiments.

(b) Concentration of surfactant: Results of the preliminary experiment involving 1000 ppm of each of 5 herbicides in combination with various concentrations of Atlox 210 indicated that (1) herbicidal activity was a function of both the herbicide application and the concentration of surfactant in the spray application; (2) the surfactant, Atlox 210 resulted in more herbicidal activity with the picloram herbicides than with the phenoxy herbicides.

In the second experiment the better surfactant, Atlox 210, was evaluated in combination with picloram K salt and Tordon 101 at 500 ppm, on balsam poplar. The results derived from visual ratings are listed in Table 8. In this table it is clearly shown that picloram was more effective than Tordon 101 and surfactant even at the lowest concentration used, very significantly improved herbicidal activity. There were, however, no clear differences between effectiveness of the various concentrations of Atlox 210 although numerically the 1% concentration was apparently superior to the lower ones. In other words, the lowest amount of surfactant was enough to improve the effect of herbicidal activity of formulations with the additive as compared with Tordon 101 without surfactant.

Table 8. Responses of balsam poplar to picloram herbicides at 500 ppm with various concentrations of surfactant. Data are means of three replicates after 2 weeks of treatment.

Herbicide	% of Atlox 210	Injury rating*
Picloram K salt	1.00	8.2
Tordon 101	1.00	7.2
Picloram K salt	0.50	7.0
Tordon 101	0.50	6.8
Tordon 101	0.25	6.8
Picloram K salt	0.25	6.4
Picloram K salt	0	2.8
Tordon 101	0	2.0

* Injury rate: 0 - no effect; 10 - complete kill. Values included by the same vertical line are not statistically different at the 1% level.

But as much as 1% additive was required to improve significantly the effect of picloram as compared with picloram itself. Accordingly, one percent of Atlox 210 was used in all later treatments.

It is of interest in this connection that Jansen et al. (25) investigated many different types of surfactants for effects on the herbicidal activity of different herbicides. They observed that phytotoxicity was most pronounced when the surfactant concentration was 1.0%. Other workers (2, 10) also reported that the concentration of surfactant in herbicides is an important factor.

(c) Effects of herbicides with surfactant on aspen and balsam

poplar: Table 9 gives the results of spray application of three herbicides used in different concentrations with Atlox 210 at 1% concentration on balsam poplar. The "F" value for differences between treatment means was statistically significant. It can be noted that the effect of picloram K salt is greater than Tordon 101 and much greater than 2,4-D amine. The surfactant, Atlox 210 as 1% of the solution improved herbicidal activity. These three chemicals with surfactant all show a sequence effect in relation to injury ratings.

Table 9. Comparison of the effect on balsam poplar of picloram, Tordon 101, and 2,4-D amine with or without Atlox 210. Data obtained from a mean of five replicates three weeks after treatment. Statistical analysis by Duncan's test (35).

Herbicide	Concentration of herbicide (ppm)	Concentration of surfactant (% v/v)	Injury rating*
Picloram K salt	2000	1.0	9.6
	1000	1.0	9.3
	2000	0	9.2
	1000	0	8.2
Tordon 101	2000	1.0	8.1
	2000	0	6.5
	1000	1.0	6.0
2,4-D amine	2000	1.0	6.0
	2000	0	5.5
	1000	1.0	5.4
Tordon 101	1000	0	5.0
2,4-D amine	1000	0	4.5

* Injury rate: 0 - no effect; 10 - complete kill. Values included by the same vertical line are not significant at the 5% level.

Two additional experiments were carried out to compare the toxic effects of some phenoxy and picloram herbicides with surfactant on aspen

and balsam poplar in the greenhouse during the winter of 1965 and in the summer of 1966. The results of the 1965 experiment showed that 3000 ppm of phenoxy herbicides and 1500 ppm of picloram with surfactant had a rapid effect on balsam poplar. Some of the treatments caused complete killing of top-growth within two weeks making it difficult to distinguish differences in herbicidal potency, because the concentrations of herbicides used were excessive for the young saplings. On the other hand, aspen poplar did not show much injury or very clear differences in response to the herbicide during the observation period. Since the aspen poplar from the plants brought in the fall had grown very little in the greenhouse during more than five months most of the leaves were old and apparently almost inactive. Hence their susceptibility to herbicides was low. Nevertheless, 2,4,5-T ester and picloram with surfactant still showed some more readily visible effects than the other treatments.

In the second experiment using young aspen trees dug up on May 5, 1966, and grown under greenhouse conditions, results were more instructive. After one month of growth aspen poplar had healthy foliage more susceptible to herbicide treatment. Four herbicides were sprayed at two lower concentrations than those used for the previous treatment. This experiment again included both aspen and balsam poplar treated with herbicides with and without surfactant. The results derived from visual ratings are listed in Table 10. The following conclusions seem to be warranted: (1) Phytotoxicity of picloram K salt was greater than that of Tordon 101 on aspen poplar, but was the reverse on balsam poplar. These results are to some extent in agreement with the observation of Watson and Wiltse (37). They found that some combination sprays of picloram herbicide with phenoxy compounds caused more rapid and uniform leaf kill of oaks (Quercus spp.) and sweet gum (Liquidambar Stryraciflua L.) than picloram alone.

[illegible]

[illegible]

Table 10. Effects of picloram and phenoxy herbicides with surfactant on foliage of aspen and balsam poplar. Data are means of ratings for three replicates two and three weeks after treatments.

Treatment*	Concentration of herbicide (ppm)	Injury rating **			
		2 weeks		3 weeks	
		Balsam	Aspen	Balsam	Aspen
Picloram	1000	3.67	3.33	4.00	3.33
Tordon 101	1000	6.00	1.33	8.00	1.33
2,4-D ester	1000	3.00	1.00	4.33	1.17
2,4,5-T	1000	3.67	2.33	5.67	2.33
Picloram	2000	5.67	9.00	7.67	10.00
Tordon 101	2000	6.33	2.67	7.33	3.33
2,4-D ester	2000	4.00	1.33	5.67	1.33
2,4,5-T	2000	4.67	3.33	7.33	3.67
Picloram (+)	500	8.00	9.67	9.67	10.00
Tordon 101 (+)	1000	8.00	7.00	9.67	7.00
2,4-D ester (+)	1000	4.00	1.33	4.67	2.00
2,4,5-T (+)	1000	4.33	4.00	5.67	4.00
Picloram (+)	1000	8.67	10.00	10.00	10.00
Tordon 101 (+)	2000	8.67	10.00	10.00	10.00
2,4-D ester (+)	2000	4.67	2.33	5.67	3.33
2,4,5-T (+)	2000	5.33	4.00	7.33	4.00

* (+) shows spray solution contained 1% v/v of Atlox 210.
** Injury scale: 0 - no effect; 10 - complete kill.

(2) It is also evident from the data in Table 10 however, that when combined with 1% Atlox 210, 500 ppm picloram was as effective or more

effective than twice as much Tordon 101 on both species. (3) 2,4,5-T was slightly more effective than 2,4-D ester on both species in all treatments. (4) 2,4,5-T ester was somewhat more effective than Tordon 101 without surfactant in top-killing of aspen poplar but not as effective as Tordon 101 against balsam poplar. However, the combination of Tordon 101 with Atlox 210 was definitely more effective than 2,4,5-T on both aspen and balsam poplar in all treatments. Figures 8 and 9 show that picloram and Tordon 101 with 1% of Atlox 210 were apparently more effective than other treatments on the balsam poplar. Similar results with aspen poplar are depicted in Figs. 10 and 11. (5) The surfactant, Atlox 210, conspicuously enhanced the herbicidal activity of picloram herbicides and only slightly improved the ester formulation of phenoxy herbicides. (6) 500 ppm of picloram with 1% of Atlox 210 was more effective than 2000 ppm of ester formulations of 2,4-D and 2,4,5-T with surfactant on both species, i.e. picloram was at least four times as effective as 2,4-D ester and 2,4,5-T with regard to top-killing in these experiments.

(d) Effect of surfactant with ester formulation of herbicides (Supplementary experiment): In the summer of 1966, an experiment was designed specifically to compare the effects of ester formulations of 2,4-D and 2,4,5-T as foliage sprays on balsam poplar. The results of observations two and four weeks after treatment are recorded in Table 11. It appears that there were not conspicuous differences between the effects of 2,4-D ester and 2,4,5-T without added surfactant, on foliage of young balsam poplar. But in the combination with surfactant most 2,4,5-T treatments were a little more effective than 2,4-D ester. Actually for practical purposes the surfactant did not greatly enhance the herbicidal activity in either ester formulations of 2,4-D or 2,4,5-T. Figures 12

Fig. 8 Comparative effects of four herbicides on foliage of balsam poplar, 19 days after treatment. From L. to R. Ck, picloram 1000 ppm, Tordon 101 1000 ppm, 2,4-D ester 2000 ppm, and 2,4,5-T 2000 ppm respectively.

Fig. 9 Surfactant enhancement of the activity of four herbicides on foliage of balsam poplar, 19 days after treatment. Ck, pic. 500(+), T.101 1000(+), 2,4-D ester 2000(+), and 2,4,5-T 2000(+) respectively (From L. to R.).

Fig. 10 Comparative effects of four herbicides on aspen poplar. 19 days after treatment. Pic. 1000, Tordon 101 1000, 2,4-D ester 2000, and 2,4,5-T 2000 respectively (L. to R.).

Fig. 11 Surfactant enhancement of the activity of four herbicides on aspen poplar, 19 days after treatment. Pic. 500(+), Tordon 101 1000(+), 2,4-D ester 2000(+), 2,4,5-T 2000(+) respectively (L. to R.).

Table 11. Surfactant enhancement of the herbicidal activity of ester formulations of 2,4-D and 2,4,5-T on balsam poplar. Data are means of scores for four replicates two and four weeks after spraying.

		Injury rating*			
	Concentra-	2 weeks		4 weeks	
Herbicide	tion	No surf.	Atlox 210	No surf.	Atlox 210
2,4-D ester	1000	1.75	1.33	3.75	4.67
	3000	2.67	2.25	5.33	7.00
2,4,5-T	1000	1.00	2.25	2.75	5.00
	3000	2.67	2.75	8.00	8.50

* Injury scale: 0 - no effect; 10 - complete kill.

and 13 also illustrate this point. These two figures show that the leaf killing, following chlorosis, was almost completely confined to the younger upper portions of the plants.

(e) Effect of surfactant on activity of picloram and 2,4-D amine formulations on potted balsam poplar plants

Picloram

Combination of picloram with surfactant showed rapid leaf burning effects which occurred within two days of treatment. Without surfactant treatments showed symptoms of injury at least four to five days or later depending upon the concentrations of picloram. The results after two weeks showed a widely different order of injury among the various concentrations of picloram with and without Atlox 210 as depicted in Fig. 14. For example Fig. 14 shows that 250 ppm of picloram with one percent Atlox 210 was more effective than 4000 ppm of picloram by itself; similarly,

Fig. 12 Comparative effects of foliage spray treatments of balsam poplar with 2,4-D ester with and without surfactant. Picture taken four weeks after treatment. CK, 3000 ppm, 3000 ppm(+) respectively (L. to R.).

Fig. 13 Comparative effects of foliage treatment of balsam poplar with 2,4,5-T ester with and without surfactant four weeks after treatment. CK, 3000 ppm, 3000 ppm(+) (L. to R.).

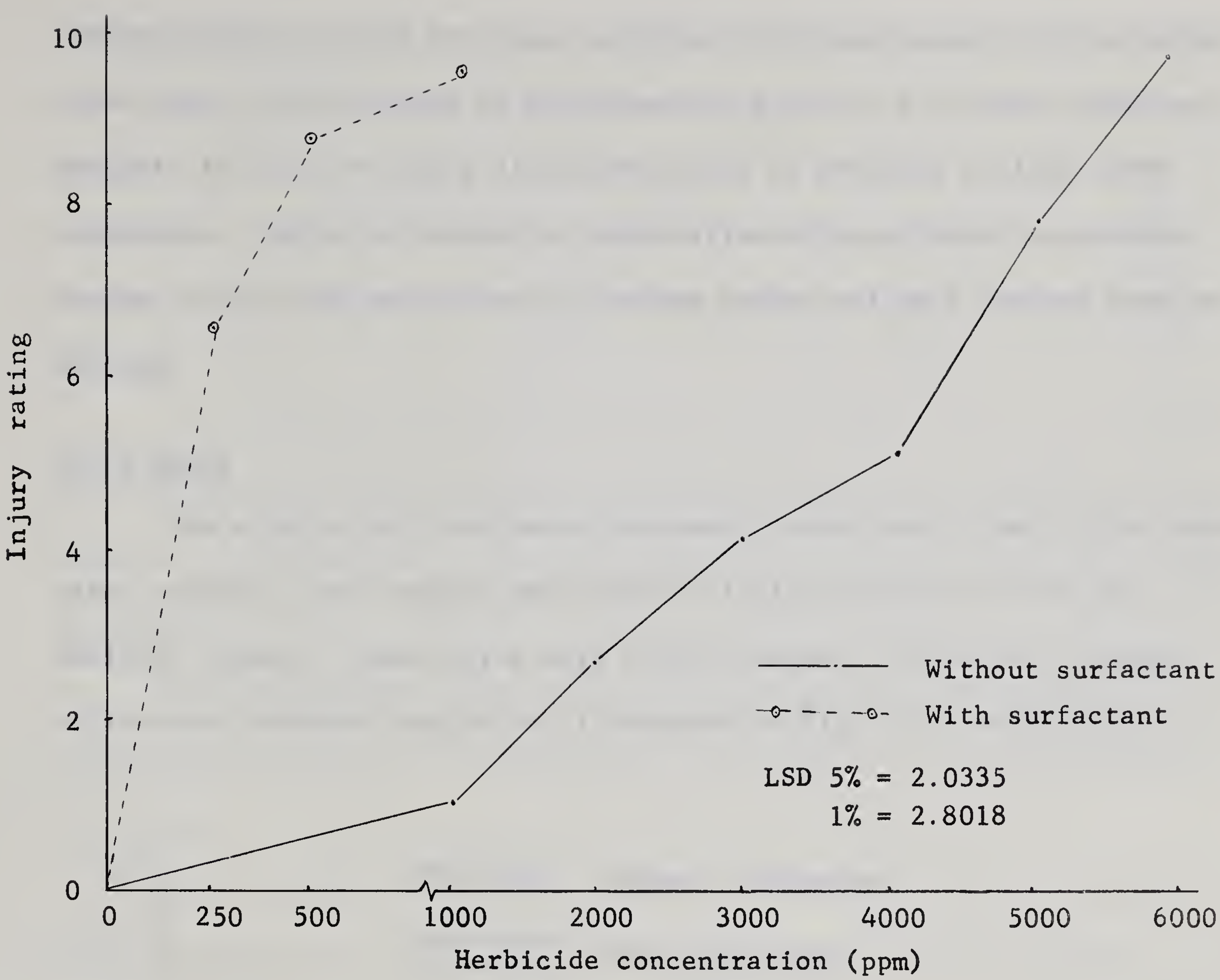


Fig. 14 Comparative effects of picloram and picloram plus surfactant on balsam poplar. Data are means of three replicates two weeks after treatment. Injury rate: 0 - no injury; 10 - complete killing of top growth.

500 ppm with surfactant is more effective than 5000 ppm without surfactant. At the same time, 1000 ppm of picloram with Atlox 210 also showed effects roughly equal to those from 6000 ppm of picloram without surfactant. Generalizing, Atlox 210 at one percent volume of spray solution with picloram K salt in this experiment was six to ten times as toxic as picloram alone on the foliage of balsam poplar.

Four weeks after spraying, plants of all treatments except 1000 ppm picloram alone, were completely killed; i.e. picloram alone at 2000

ppm was enough to kill the young saplings of balsam poplar in this greenhouse trial. This dosage is approximately equal to 0.67 lb/A, which was adequate to kill the young plants described in previous foliage spray treatments. Using surfactant in combination with picloram the minimum dosage to kill the young trees of balsam poplar was much reduced down to 250 ppm.

<u>2,4-D amine</u>

The effects of 2,4-D amine treatment showed very slowly. Two weeks after spraying, the largest rate showed little superiority over the smallest dosage. Twenty five days after treatment, there were clearer differences between results as illustrated in Fig. 15. Analysis of

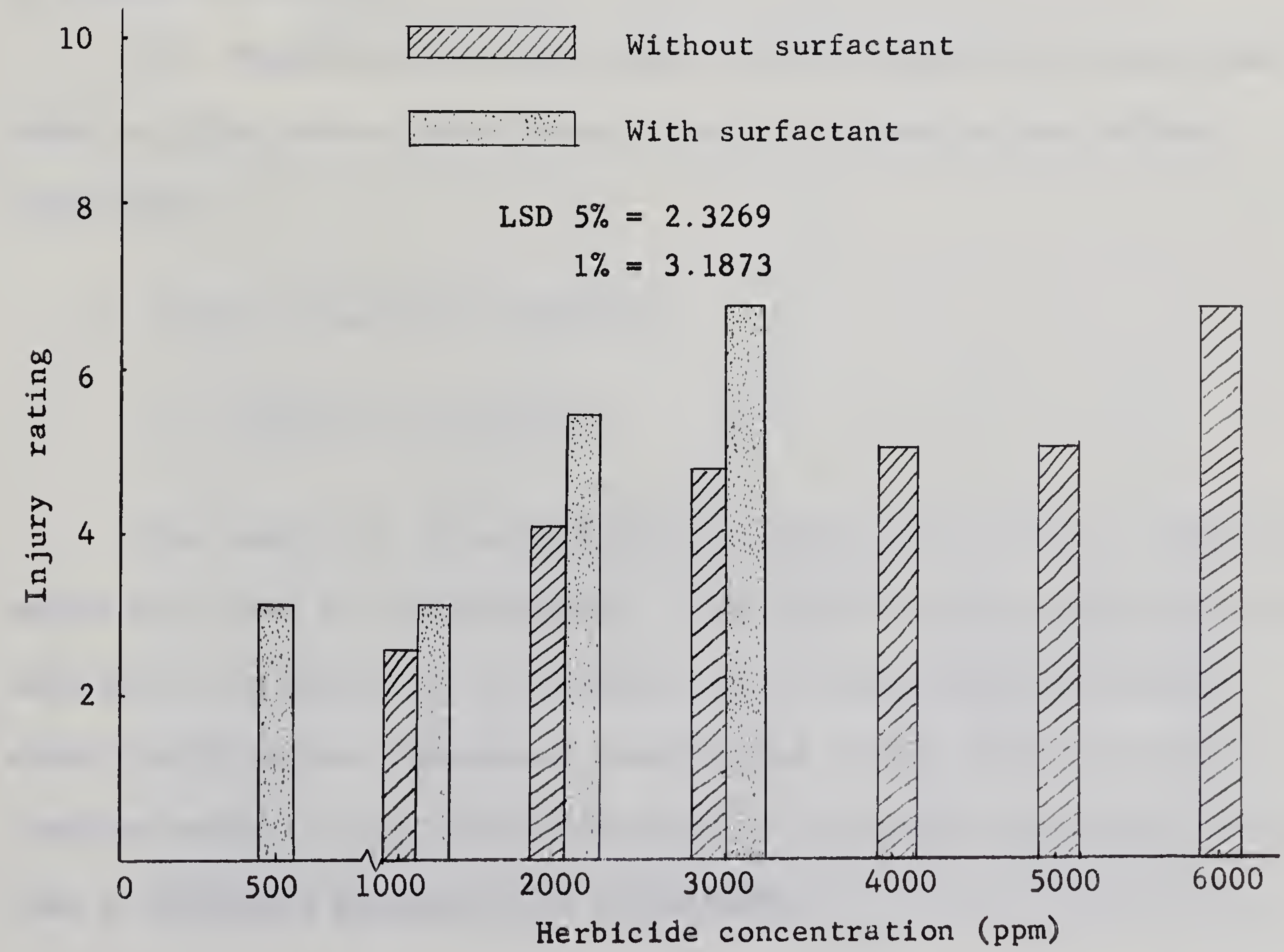


Fig. 15 Comparative effects of 2,4-D amine with 1% of Atlox 210 on balsam poplar. Data are means of three replicates, 25 days after treatment. Injury rate: 0 - no effect; 10 - complete top killing.

variance performed on the visual ratings of injury showed highly significant differences among treatment means. From Fig. 15 four points seem clear.

(1) 2,4-D amine was not very toxic to balsam poplar; even the highest concentration, 6000 ppm still had not completely killed the young saplings.

(2) Although the effects of treatments without surfactant were not much different even, for example, between the treatments of 2000 ppm and 5000 ppm, nevertheless, there was a gradually increasing effect as dosage increased.

(3) Surfactant, Atlox 210 showed considerable enhancement of the herbicidal activity in all treatments; this result is shown pictorially in Figures 16 and 17.

(4) Surfactant with 500, 2000, and 3000 ppm of 2,4-D amine was about as effective as twice these respective concentrations without surfactant.

4. Partial immersion treatments

A. Materials and methods

Four month old young saplings of balsam poplar about 24 inches in height were used in this experiment. The upper 12 inches from the tip of each plant was marked off by a plastic ribbon for chemical treatment above the ribbon and subsequent observations of any effects of translocation below it. Six herbicides were used at several concentrations and some of them were combined with surfactants.

The pots were inverted during dipping of the upper shoot region

Fig. 16 Control of balsam poplar 45 days after treatment with 2,4-D amine at four concentrations. CK, 1000, 2000, 3000 and 4000 ppm respectively (L. to R.)

Fig. 17 Surfactant enhancement of the activity of 2,4-D amine on balsam poplar, 45 days after treatment. CK, 500(+), 1000(+), 2000(+), 3000(+) (L. to R.)

in herbicidal solution for a few seconds and then allowed to dry in this position on a frame before returning them to the greenhouse bench. A total of 116 pots were used in four randomized blocks for treatments as tabulated below.

Herbicide	Concentration (ppm) Without surfactant	With surfactant (1% v/v)
Picloram K salt	1000	250 + Atlox 209
	2000	250 + Atlox 210
		500 + Atlox 209
		500 + Atlox 210
Tordon 101	1000	500 + Atlox 210
	2000	1000 + Atlox 210
2,4-D amine	1000	1000 + Atlox 209
	2000	1000 + Atlox 210
		2000 + Atlox 209
		2000 + Atlox 210
2,4-D acid	1000	1000 + Atlox 210
	2000	2000 + Atlox 210
2,4-D ester	1000	1000 + Atlox 210
	2000	2000 + Atlox 210
2,4,5-T	1000	1000 + Atlox 210
	2000	2000 + Atlox 210

B. Results and discussion

Plant responses to the herbicides began to appear within the first week after the treatments and a week later maximum differences between treatments were visible. Ratings are charted in Fig. 18. Again it is seen that in combination with surfactants, picloram formulations were more effective than phenoxy herbicides. Both Atlox 209 and 210 highly

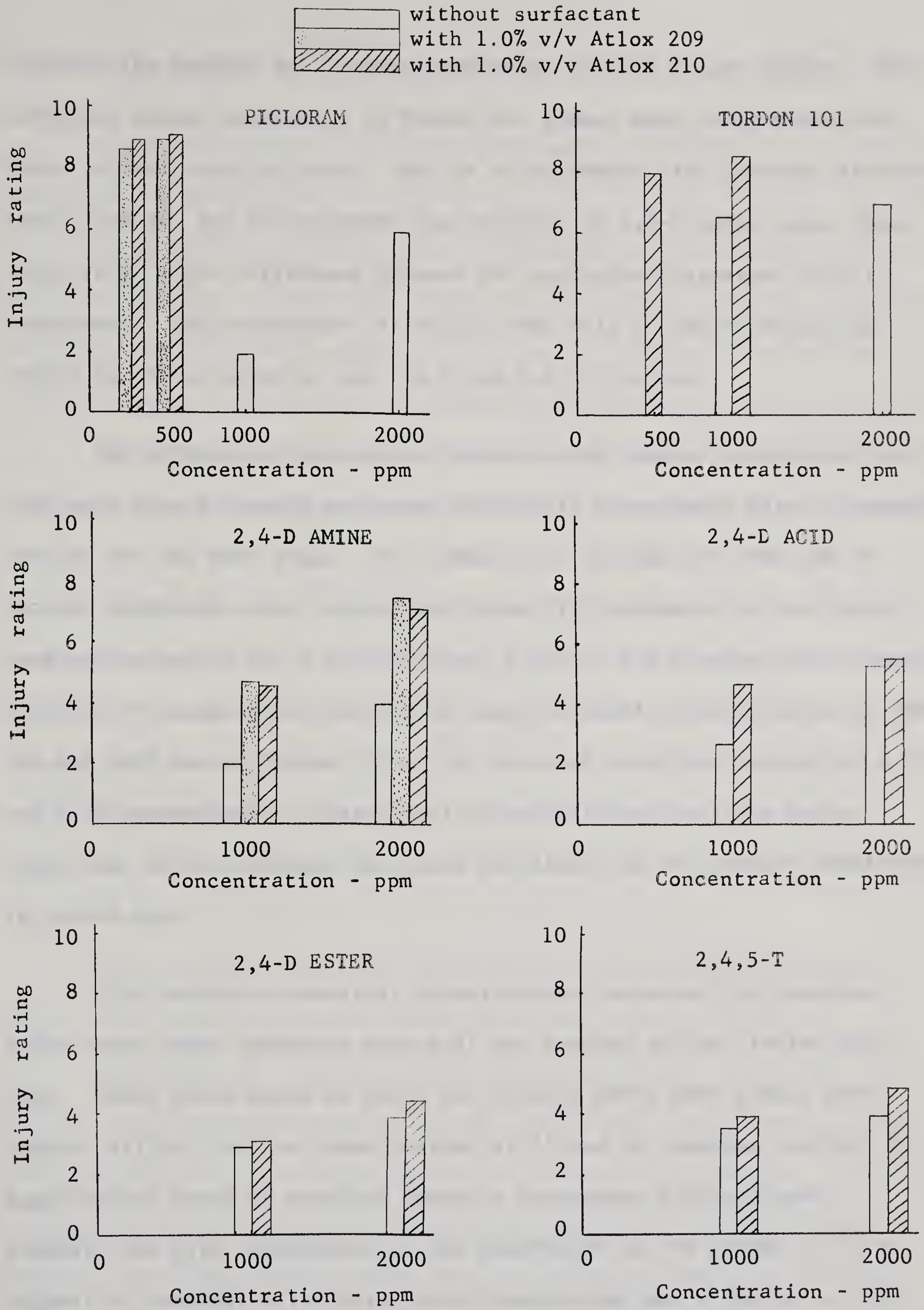


Fig. 18 Effects on balsam poplar of partial immersion treatment in picloram and phenoxy herbicides. Data are means of four replicates, 14 days after treatment. Injury rate: 0 - no effect; 10 - complete kill of treated part.

improved the ability of picloram herbicides to kill balsam poplar. With herbicide alone, treatments of Tordon 101 seemed more uniform and with faster effect than picloram. This is in agreement with previous discussion. Both Atlox 209 and 210 enhanced the activity of 2,4-D amine also; there being very little difference between the surfactants apparent in this experiment. The surfactant, Atlox 210, had only a limited enhancing effect on the activity of the 2,4-D and 2,4,5-T esters.

The effects on young shoots treated with phenoxy herbicides developed more slowly showing much more distinctly three weeks after treatment than at the two week stage. For example the ratings for 2000 ppm of phenoxy herbicides with one percent Atlox 210 treatments at the three week period were 8.75, 8.25, 8.00, and 8.25 for 2,4-D amine, acid, ester, and 2,4,5-T respectively; while the same treatments with picloram at 500 ppm and 1000 ppm of Tordon 101 at the two week stage had ratings of 8.75, and 8.10 respectively. These results indicate that picloram had at least four fold and Tordon 101 twice the effect of the phenoxy herbicides as judged here.

With regard to potential translocation responses the symptoms after upper shoot immersion were wilt and burning on the treated part only. After three weeks of trial all treated parts were almost completely killed; but the lower foliage still had no symptoms contrary to expectations based on previous opposite experience with picloram. Probably the high temperature in the greenhouse in the summer (35°C or higher) in contrast with winter-time temperatures was a factor in this connection. One might expect rapid foliar absorption of the herbicides (30) and resultant fast-action to kill the treated part only, blocking effective translocation.

5. Conclusions

The major findings in all the greenhouse experiments may be briefly summarized as follows.

(1) Picloram potassium salt, although not as fast-acting as 2,4-D and 2,4,5-T ester in the early stages after treatment, was the most effective in killing tops and roots of the saplings. About 0.7 lb/A of the picloram killed the saplings as compared with about 2.6 lb/A of the esters.

(2) The amine form of 2,4-D was less injurious than esters to foliage but in some cases affected the roots to a greater extent than did esters.

(3) Surfactant at all concentrations used here, improved herbicidal activity. Surfactants highly enhanced the activity of picloram herbicides, moderately improved the amine of 2,4-D and had little effect on the other phenoxy herbicides. However, the activity of 2,4,5-T was increased a little more than was that of 2,4-D ester. There was no significant difference between concentrations of wetting agent used, even though the greatest amount appeared to be best in several cases.

(4) The surfactant Atlox 210 was for the most part superior to Atlox 209 in enhancement of visible herbicidal injury to plants.

(5) Tordon 101 (which combines 20% picloram amine and 80% 2,4-D amine), was more effective than 2,4,5-T in killing the foliage of balsam poplar; however, on the aspen poplar, the result was opposite. A partial explanation may be that picloram without added surfactant penetrates balsam poplar more readily than aspen poplar since Tordon 101 combined with surfactant was conspicuously more effective than 2,4,5-T on both aspen and balsam poplar.

III. Field experiments with herbicides and surfactants on aspen and balsam poplar

Field experiments were conducted at the University of Alberta farm at Ellerslie, Alberta, about 10 miles south of Edmonton, during the summers of 1965 and 1966, and at Miquelon Lake, approximately 40 miles southeast of Edmonton during the summer of 1966. Ellerslie farm is situated in black soil area and Miquelon Lake is situated in grey wooded soil area of Alberta. Both are farming areas having scattered stands of aspen and balsam poplar as the dominant native species.

1. Foliage dipping treatments

A. Materials and methods

In order to be able to observe results of downward movement, if any, of herbicides applied to upper parts of trees, the terminal branches of young aspen and balsam poplar up to 10 feet tall, growing in native stands, were treated in the summer of 1965 at Ellerslie farm. These trees were from sucker growth from associated mature parent plants. The first experiment in randomized block design tested the effect of several herbicides on aspen and balsam poplar. In a second similar experiment, effects of herbicides with or without added surfactant Atlox 210 were used on balsam poplar only.

In the first experiment, 360 young trees of balsam poplar and the same number of aspen poplar were used for dipping. Plots were prepared for herbicidal treatment by dividing the experimental areas into 8 blocks. Each block contained 9 treatments and 5 replicates in each treatment. The herbicides included were Tordon 101; 2,4-D amine (with

and without 1% Atlox wetting agents); 2,4-D acid; 2,4-D ester; 2,4-D emulsamine; 2,4,5-T; and silvex.

Herbicide was applied by bending and dipping terminal branches of the trees to a depth of approximately 20 inches in cylinders containing 2000 or 4000 ppm herbicide solutions on July 5, 1965. After one week and three weeks results based on a visual rating from 0 to 10 were recorded and later analysed using Duncan's test to compare the differences in speed and extent of injury from the herbicide preparations.

In a second field experiment with balsam poplar, similar procedure was followed using 1000 and 3000 ppm concentrations of herbicides. Four herbicides were used with two treatments in randomized block design to compare effects of herbicides with or without added surfactant Atlox 210. Six blocks and four replications of each treatment were treated on August 11, 1965. Periodic visual ratings were noted and actual measurements of lengths of chemically injured portions of branches were recorded four weeks after treatment. Duncan's test was used to define significant differences between treatment means.

Moreover, in the summer of 1966, the lengths of visibly injured portions of branches in the second experiment were again measured to reveal any progression of symptoms of injury over the previous winter and spring periods.

B. Results and discussion

Data presented in Table 12 show that after one week of treatment there were recognizable differences in speed of injury from the low dosages, but the high rates were not significantly different. After

Table 12. Comparisons of the herbicidal effects of several herbicides on balsam poplar, using Duncan's test.

Treatment	Injury rating (a)			
	2000 ppm		4000 ppm	
	1 wk	3 wk	1 wk	3 wk
	(b) *	**		**
Tordon 101	7.50 a	8.80 a	7.75	10.00 a
2,4-D amine	4.25 bc	5.50 c	5.50	6.25 b
2,4-D amine + 209	5.00 bc	6.00 bc	6.00	8.50 ab
2,4-D amine + 210	6.50 ab	8.50 ab	5.75	8.75 a
2,4-D acid	4.00 c	6.80 abc	6.75	9.25 a
2,4-D ester	5.00 bc	8.80 a	6.50	9.25 a
2,4-D emulsamine	5.25 bc	7.00 abc	6.00	8.50 ab
2,4,5-T	5.75 abc	9.00 a	6.50	9.25 a
Silvex	4.50 bc	8.80 a	5.50	9.50 a

(a) Injury rate: 0 - no effect; 10 - complete kill. Data are means of 4 replicates.

(b) Means within a column followed by the same letter are not significantly different at the 5% level (*) and the 1% level (**).

three weeks however the treatment means showed highly significant differences for both rates.

One week after application Tordon 101 was most effective. This confirmed the result of greenhouse treatments in which ester showed faster effect during the first few days, but after 5 - 7 days, picloram equalled or surpassed the ester. Generally, 2,4-D amine was slower and less effective than other chemicals, but added Atlox 210 caused appreciable improvement. This was apparent even though the difference was not always statistically significant. This also agrees with the results

which occurred in the greenhouse showing that surfactant improved herbicidal activity. Ester formulations were high in rank of effect probably owing to the ready penetration into the plant tissue of these oily substances.

Additional observations were recorded three weeks after treatment. There were some effects which were different from those shown earlier. First, over the long period, differences between herbicides became less distinguishable. Secondly, the higher rate, 4000 ppm had the most nearly complete effect. Thirdly, Tordon 101 and ester formulations still showed superiority in killing foliage. Fourthly, surfactant significantly improved 2,4-D amine activity. In both rates, the fact that amine with 210 wetting agent was greater than amine with 209 is a very interesting point. This confirmed the greenhouse results showing superiority of Atlox 210 mentioned earlier.

The results for aspen poplar compared in the same way after one week and three weeks of treatment are listed in Table 13. From comparisons in Table 13 it can be noted that in the early period the higher rate caused more conspicuous difference between treatment means than did the lower rate. 2,4,5-T and silvex esters were more effective than Tordon 101 on aspen poplar. 2,4-D amine was least effective and added Atlox 210 induced a significant difference; this result was similar to that for balsam poplar.

The results three weeks after dipping were in general quite similar to those which occurred in one week. There were still some differences in herbicidal effects of both the 2000 and the 4000 ppm rates on aspen poplar compared with those noted with balsam poplar. Firstly, 2,4,5-T and

Table 13. Comparisons of the effects of herbicides on aspen poplar, using Duncan's test.

	Injury rating [(a)]			
	2000 ppm		4000 ppm	
Treatment	1 wk	3 wk	1 wk	3 wk
	(b)			
Tordon 101	5.50 b	6.75 b	7.25 bc	8.50 b
2,4-D amine	3.50 c	4.50 c	4.00 e	5.00 c
2,4-D amine + 209	4.50 bc	5.50 bc	5.50 de	6.50 c
2,4-D amine + 210	5.75 b	6.75 b	6.25 cd	7.25 c
2,4-D acid	5.00 bc	6.00 bc	5.25 de	6.50 c
2,4-D ester	6.00 b	6.50 bc	5.75 cd	6.50 c
2,4-D emulsamine	5.75 b	6.00 bc	5.50 de	6.50 c
2,4,5-T	8.50 a	9.50 a	9.00 a	10.00 a
Silvex	6.25 ab	7.50 ab	8.25 ab	9.50 ab

(a) Injury scale: 0 - no effect; 10 - complete kill. Data used are means of 4 replicates.

(b) Means within a column followed by the same letter are not significantly different at the 1% level.

silvex were more effective than other herbicides including Tordon 101 mixture containing picloram which was most effective against balsam poplar. Secondly, the ranking of effects of the top four chemical treatments, 2,4,5-T, silvex, Tordon 101, and 2,4-D amine with Atlox 210, were the same for both rates. Moreover, 2,4-D amine with Atlox 210 was significantly more effective than without surfactant in both cases. Thirdly, the several formulations of 2,4-D were less effective than 2,4,5-T and silvex as noted in Table 13. Fourthly, 2,4-D amine was still least effective on aspen poplar as it was on balsam poplar.

In the second field experiment in 1965 actual measurements of lengths of extension of visible herbicidal injury along the treated branches of balsam poplar were recorded in addition to rating the intensity of toxic effect 0 - 10. The data for measurements of lengths of injured sections of the branches four weeks and ten months after treatment of the standard length are presented in Table 14.

Table 14. The lengths in inches of injured shoots of balsam poplar during 1965 and 1966 following dipping of the terminal 20 inch portions of the shoots. Data are means of 12 replicates.

		1000 ppm		3000 ppm	
	Herbicide	Without surfactant	With Atlox 210	Without surfactant	With Atlox 210
*I	Tordon 101	19.8	29.7	22.3	31.2
	2,4-D amine	16.0	13.5	7.7	23.0
	2,4-D ester	11.0	10.2	18.3	26.0
	2,4-D salt	0.5	3.3	4.2	18.2
II	Tordon 101	36.08	38.17	34.67	48.33
	2,4-D amine	33.00	36.92	39.42	42.92
	2,4-D ester	35.42	38.58	38.92	39.67
	2,4-D salt	34.33	34.08	32.08	36.83

* I: measured after 4 week period; II: measured after ten months.

The results of measurement of the lengths of injured shoots showed that wetting agent very significantly improved the visible effects of Tordon 101 applied at the 1000 ppm rate and of all herbicide formulations applied at the 3000 ppm rate during 1965. At both rates Tordon 101 was

most effective and 2,4-D salt was least effective. Tordon 101 and 2,4-D amine were the more freely translocated judging by the lengths of branch visibly affected. However, the injury during the first summer, to amine treated shoots was not more severe than to ester treated shoots. The results of visual ratings were in general in agreement with those just described in measurements. Surfactant clearly improved the herbicidal activity. Atlox 210 enhanced 2,4-D amine obviously more than the other formulations of 2,4-D. These results are similar to those obtained in the greenhouse.

After the winter and spring, the lengths in inches of injured shoots were measured again on June 17, 1966. The results (Table 14) confirmed the results of measurement and visual ratings of 1965. Apparently, over a long time the lengths of injured shoots showed less differences among the treatment means and gradually became less distinguishable. Nevertheless, it was noted that Tordon 101 still was most effective and 2,4-D salt was least effective. Surfactant, Atlox 210 clearly enhanced the herbicidal activity of all treatments. The 3000 ppm Tordon 101 and 2,4-D amine showed more enhancement from added Atlox 210 than did other formulations of 2,4-D. Jansen (24) studied the surfactant-amine salts of 2,4-D on soybean and found that the total system in which a herbicide is applied to the plant governs the activity of the toxic component. He stated that both herbicidal and surfactant structural characteristics were achieved in the same molecule, and the surfactant structure exerted a controlling influence on the activity of the herbicide moiety. In other words the effect of the added surfactant may not be due simply to facilitation of penetration of greater amounts of herbicide.

2. Foliage spray treatments

A. Materials and methods

Two field sites were established for the evaluation of herbicides on balsam and aspen poplar along the southwestern shore of Miquelon Lake.

The first experiment was a randomized block design with two replications for each herbicidal treatment to test the effects of herbicidal sprays on balsam poplar 6 - 10 feet tall. The plot size was 40 x 10 feet leaving a 10 foot unsprayed strip between plots. Herbicides used were picloram K salt, Tordon 101, 2,4-D amine, 2,4-D acid, 2,4-D ester, and 2,4,5-T all without added surfactant. In addition the surfactant, Atlox 210, was used at 1% concentration in combination with all herbicides except 2,4-D ester. Each plot was sprayed with one gallon of solution. Picloram formulations were used at 750 ppm (approximately 0.75 lb/A rate) and the other herbicides at 1500 ppm equivalent to approximately 1.5 lb active ingredient in 100 gal/A. Application of the herbicide solutions was by a Spray-Systems Gunjet fitted with an A4HSS-45 cone pattern nozzle (National Grain Co., Winnipeg, Manitoba). Pressure of 100 psi was supplied from a gasoline engine driven compressor with clamped-top paint tank connected to the gunjet sprayer. Twenty-two plots were sprayed on June 16, 1966. After treatment the indices of visual severity of injury to the foliage were recorded at 1 - 5 weeks and statistical analysis was used to compare the treatment means.

The same herbicides used in the first experiment were applied in the second experiment to study the effects of herbicides on aspen poplar. The herbicides evaluated in the experiment included: picloram K salt

0.5 lb/A, Tordon 101 1 lb/A, and 1.5 lb/A of the phenoxy herbicides. Surfactant Atlox 210 at 1% concentration was also added to all spray solutions, except 2,4,5-T and herbicides-alone treatments. One additional treatment was made, namely Atlox 210 at 1% concentration to check the effect of surfactant alone on aspen poplar.

Young aspen trees in the site for treatment were 10 - 15 feet in height. The plot size was 25 x 25 feet leaving a 10 foot unsprayed strip between the plots.

Spray equipment consisted of a hand-gunjet fitted with an off-centre fan type (OC-40) nozzle (National Grain Co., Winnipeg) giving a spray 25 feet in depth and 15 feet in vertical height of swath coverage at 100 psi.

Twenty-three plots were sprayed on June 23, 1966, and were evaluated at 1, 2, 3, and 4 weeks after herbicidal treatment by visually estimating indices of foliage kill.

B. Results and discussion

<u>Balsam poplar</u>

Visible effects of herbicides on the foliage of balsam poplar at first week after spraying were slight. Leaf burning with bending was observed in most plots; few distinguishable differences were evident among the treatments. Nevertheless picloram with surfactant treatment showed better than others. Two weeks after commencement of the experiment the picloram treatments were highly significantly different from other treatments. Table 15 summarizes the results recorded two and four weeks after the tests were begun.

Table 15. The effects of foliage sprays of picloram and phenoxy herbicides with and without surfactant on balsam poplar. Data are means of two replicates 2 and 4 weeks after treatment.

Herbicide and dosage		Injury rating (a)			
		Without surfactant		With Atlox 210	
		2 wk	4 wk	2 wk	4 wk
Picloram K salt	0.75 lb/A	5.25**	9.75*	8.50**	10.00**
Tordon 101	0.75	2.50**	6.38	3.25	9.25**
2,4-D amine	1.5	1.25	3.38	1.88	3.00
2,4-D acid	1.5	1.88	3.25	2.38	4.13
2,4-D ester	1.5	1.50	3.13	-	-
2,4,5-T	1.5	1.38	3.63	2.13	5.25
LSD 5% *		1.58	3.61	2.29	2.45
1% **		2.49		3.80	4.07

(a) Injury rate: 0 - no effect; 10 - complete kill of top growth.

From Table 15 three points seem important. (1) Picloram K salt was most effective in top killing of balsam poplar, and added surfactant improved the result. 2,4-D amine was least effective. (2) Tordon 101 was less effective than picloram in both treatments, with and without surfactant, at early stages. Four weeks after spraying, however, it gradually began to overtake picloram and the difference became less distinguishable. (3) The effects of phenoxy herbicide treatments were least distinguishable. Although surfactant with 2,4,5-T seemed a little more effective than others, it was not statistically different.

These results were quite similar to those from greenhouse treatments. Picloram at 0.75 lb/A was enough to completely kill top growth

of the young trees within four weeks (Fig. 19 and 20). Picloram and Tordon 101 at their low dosages were more effective than phenoxy herbicides at 1.5 lb/A.

Fig. 19 Balsam poplar four weeks after foliage spraying in 1966 with picloram.

Fig. 20 Young balsam poplar four weeks after spraying with picloram and surfactant in 1966.

Bovey and coworkers (4) provided some information which showed that picloram was most effective to control many brushy species in range land of Texas. They found that picloram in many cases was more effective than the phenoxy herbicides and some other herbicides such as dicamba, paraquat and bromacil for brush control. The Dow Chemical Co. research workers also reported that picloram was much more effective than other currently used herbicides to control Macartney rose (10) and some other woody plant species (13, 17, 34, 36, 37, 38) and deep-rooted perennial weeds (20). Although there is very limited information dealing with balsam poplar control (34) and the studies need to be extended to include observations on survival and sucker growth during the following year the present results do indicate superiority of picloram in conformity with the results of other workers for other perennial species.

Aspen poplar

In general the results with aspen poplar were quite similar to those obtained from the dipping treatments with aspen poplar at Ellerslie and from the foregoing foliage spraying of balsam poplar with regard to speed and extent of herbicidal toxicity. Differences were clearest during the second and fourth week after spraying. The results derived from a rating of visual severity of foliage injury on aspen poplar are listed in Table 16. These results show that in the second week after treatment the effects of different herbicide treatments were not significantly different but 2,4,5-T had a little faster effect than other herbicides. For example, Tordon 101 at first was less effective but by the fourth week its extent of injury was similar to that of 2,4,5-T. However, with added surfactant the picloram formulations were significantly superior

Table 16. Foliage injury of aspen poplar by picloram and phenoxy herbicides two and four weeks after spraying.

Herbicide and dosage		Injury rating (a) Without surfactant 2 wk	4 wk	With Atlox 210 2 wk	4 wk
Picloram K salt	0.5 lb/A	2.63	9.50*	4.38*	10.00**
Tordon 101	1.0	2.50	9.13*	3.75*	9.63**
2,4-D amine	1.5	1.13	1.63	1.25	1.88
2,4-D acid	1.5	1.75	9.25*	2.00	8.75**
2,4-D ester	1.5	1.38	6.63*	1.75	6.00**
2,4,5-T	1.5	2.88	7.13*	-	-
LSD 5% *			4.56	1.64	2.08
1% **					3.45

(a) Injury rate: 0 - no effect; 10 - complete kill of top growth. Data are means of two replicates.

to phenoxy herbicides during the observation period. Picloram potassium salt was most effective. At the rate of 0.5 lb/A it was a little more effective than Tordon 101 at 1 lb/A and was much more effective than phenoxy herbicides at 1.5 lb/A. Surfactant improved herbicidal activity of picloram formulations more than that of other treatments. All of these results were very similar to those from the foliage spraying of balsam poplar. However, the effects of phenoxy herbicides except 2,4-D amine were quite severe at the fourth week observation time as compared with balsam poplar at the same period. That is these results suggest that aspen poplar was easier to kill than balsam poplar.

Surfactant Atlox 210 at 1% concentration by itself had no effect whatever. This result was the same as found in various greenhouse treatments. The marked enhancement of herbicidal activity by added surfactant may be due to the synergistic effect of herbicides and surfactant (11). As indicated earlier the surfactant in association with sprays might have multiple effects aiding emulsification, differential wetting, spreading, adherence of spray solutions on plant leaf surfaces, solubilization and reactivity of herbicides (12, 14, 25, 32).

The results from picloram in this experiment seem to be in accord with the results of a field experiment reported by Watson and Wiltse (37). In a test conducted in Michigan they showed that Tordon herbicide at 0.5 lb/100 gallons caused complete top-kill without resprouting of many brushy species including aspen poplar and eastern cottonwood (Populus deltoides Bartr.) when evaluated a year following treatment. Schwartzbeck and Wiltse (34) also reported that aspen poplar was completely killed with picloram at 0.4 lb/100 gallons while 2,4,5-T at 4 lb/100 gallons killed only 90% of the growth.

3. Conclusions

The observations recorded during the early period following spray treatments with several formulations of each of picloram and phenoxy herbicides support the view that (a) smaller amounts of picloram and picloram mixtures than of phenoxy herbicides would have been adequate to kill both aspen and balsam poplar and (b) aspen poplar was more susceptible to injury than was balsam poplar. Moreover, herbicide solutions with added surfactant were definitely more effective than the herbicide alone, especially with the picloram herbicides in both dipping and spray

treatments. Picloram potassium salt was most effective and 2,4-D amine was least effective in most experiments.

On aspen poplar, unlike on balsam poplar, silvex and 2,4,5-T appeared somewhat superior to Tordon 101 and 2,4-D as regards visible response at the time of the early observations in the season of application. However, Tordon 101 with added surfactant was definitely more effective than 2,4,5-T.

The differences between effects of most treatments were clearest during the second to fourth week after treatment.

The cone nozzle was superior to the off-centre OC-40 nozzle as regards uniformity of spray coverage of foliage. It is, however, less satisfactory than the off-centre fan type nozzle when a large swath is desirable.

GENERAL SUMMARY

Two formulations of picloram and seven formulations of phenoxy herbicides were used in this research for study of control of aspen and balsam poplar.

With regard to foliage, ester formulations of 2,4-D and 2,4,5-T were faster and more effective than other formulations of 2,4-D. However, ester apparently did not translocate as well as other formulations used with cuttings or in the field. These results are in agreement with the results of tree injection experiments reported by Corns and Schraa (8).

The surfactant Atlox 210 was in most instances superior to another of the manufacturer's top selections, Atlox 209, in improving the results from the various herbicides used in the series of greenhouse and field experiments. Both surfactants Atlox 209 and 210, however, improved herbicidal activity. This was particularly noticeable with upper foliage treatments with 2,4-D amine which by itself was among the least effective of the treatments. This aspect deserves additional attention in view of the minimal volatility hazards from amines.

The new herbicide picloram (trade name Tordon) and picloram mixtures at rates comparable to those for the other herbicides used, were superior in visible toxicity in all treatments for killing of foliage parts of plants in field and greenhouse and the roots of greenhouse plants. This therefore may be of considerable significance in relation to prevention of sucker growth under practical conditions. Economic aspects of use of picloram for brush control are important. Picloram is more than twenty times as expensive as 2,4-D per pound and is about four times as effective,

i.e. about five times as expensive to use. However, added surfactant with picloram showed toxicity sometimes about ten times as great as from picloram alone. Therefore, the picloram-surfactant combination for brush control may prove to be very practical if the cost of the surfactant turns out to be reasonable, and additional, longer term studies should receive priority. The basic question as to whether Atlox 210 has a beneficial effect in addition to assistance with penetration of the herbicide also seems very worthy of attention. Moreover, in this connection the 2,4-D formulations with the added wetting agent, though less effective than picloram, deserve further attention in view of the promising results obtained from addition of surfactant to those cheaper products.

Silvex and 2,4,5-T were soon after application somewhat more effective than 2,4-D and Tordon 101 in top killing of aspen poplar but were not as effective as Tordon 101 against balsam poplar. As time after application lengthened, toxic effects of Tordon 101 tended to overtake and surpass those of 2,4,5-T. Moreover, Tordon 101 with added Atlox 210 surfactant was definitely much more effective than 2,4,5-T in the field and greenhouse trials on both aspen and balsam poplar. In general it appears that the extent of superiority of 2,4,5-T ester over 2,4-D ester is not great enough to warrant preference for use of 2,4,5-T instead of 2,4-D on aspen and balsam poplar. As indicated earlier the potential practical economic justifiability of picloram combinations as herbicides of choice for brush control deserves additional study.

REFERENCES

1. Arnold, W. R. and P. W. Santelmann. 1966. The response of native grasses and forbs to picloram. Weeds 14:74-76.

2. Behrens, R. W. 1964. The physical and chemical properties of surfactants and their effects on formulated herbicides. Weeds 12:255-258.

3. Bird, R. D. 1961. Ecology of the aspen parkland of western Canada. Canada Dept. Agr., Res. Branch Pub. 1066. 155pp.

4. Bovey, R. W., F.S. Davis, M. G. Merkle, R. E. Meyer, H. L. Morton and L. F. Bouse. 1965. Defoliation and control of brush. Proc. SWC. 18:288-292.

5. Brown, A. B. 1935. Cambial activity, root habit and sucker shoot development in two species of poplar. New Phytologist 34: 163-179.

6. Cormack, R. C. H. 1965. The effects of calcium ions and pH on the development of callus tissue on stem cuttings of balsam poplar. Can. J. Botany 43:75-83.

7. Corns, W. G. 1965. Unpublished data.

8. Corns, W. G. and R. J. Schraa. 1964. Comparative effects of various herbicides injected into the trunks of balsam poplar (Populus balsamifera). NWC:256.

9. Corns, W. G. and R. J. Schraa. 1965. Mechanical and chemical control of silverberry (Elaeagnus commutata Bernh.) on native grassland. Jour. Range Mangt. 18:15-19.

10. Cozart, E. R. 1965. Reclamation of Macartney rose infected fence rows with Tordon herbicide. Down to Earth 21(1-2):15-18.

11. Crafts, A.S. 1962. The chemistry and mode of action of herbicides. Interscience Publishers, N.Y. 269pp.

12. Currier, H. B. and C.D. Dybing. 1959. Foliar penetration of herbicides - review and present status. Weeds 7:195-213.

13. Ferguson, R. H. 1965. Tordon controls range brush in New Zealand and Australia. Down to Earth 21(3):18-21.

14. Foy, C. L. 1964. Review of herbicide penetration through plant surfaces. J. Agri. Food Chem. 12:473-476.

15. Friesen, H. A., M. Aaston, W. G. Corns, J. L. Dobb and A. Johnston. 1965. Brush control in western Canada. Canada Dept. Agr. Bull. 1240. 26 pp.

16. Gakenheimer, W. C. 1965. Herbicidal adjuvants. Paper presented at the meeting of the Society of Chemical Industry. London, England. March 30-31, 1965. (Courtesy Atlas Chemical Co.)

17. Gantz, R. L. and E. R. Laning, Jr. 1963. Tordon for the control of woody rangeland species in the western United States. Down to Earth 19(3):10-13.

18. Goring, C. A. I., C. R. Youngson and J. W. Hamaker. 1965. Tordon herbicide disappearance from soils. Down to Earth 20(4): 3-5.

19. Hamaker, J. W., H. Johnston, R. T. Martin, C. T. Redemann. 1963. A picolinic acid derivative: a plant growth regulator. Science 141:363.

20. Heiker, E. E. 1964. Tordon and other herbicides - field testing for the control of deep-rooted perennial weeds in Colorado. Down to Earth 20(3):9-12.

21. Hetherington, J. C. 1964. Brush control in coastal British Columbia. Research notes of British Columbia Forest Service. Victoria, B. C., Canada. 56 pp.

22. Hurtt, W. and C. L. Foy. 1965. Some factors influencing the excretion of foliarly-applied dicamba and picloram from roots of Black Valentine beans. Plant Physiol. Supp. 40:48.

23. Jansen, L. L. 1964. Relation of structure of ethylene oxide ether-type nonionic surfactants to herbicidal activity of water-soluble herbicides. J. Agri. Food Chem. 12:223-227.

24. Jansen, L. L. 1965. Herbicidal and surfactant properties of long-chain alkylamine salts of 2,4-D in water and oil sprays. Weeds 13:123-130.

25. Jansen, L. L., W. A. Gentiner and W. G. Shaw. 1961. Effects of surfactants on the herbicidal activity of several herbicides in aqueous spray systems. Weeds 9: 381-405.

26. Klingman, G. C. 1961. Weed control: as a science. 421 pp. John Wiley & Sons, Inc., N. Y. (pp. 303-320).

27. Leonard, O. A. 1963. Translocation of herbicides in woody plants. Proc. Amer. Soc. Foresters 99-103.

28. Leonard, O. A. and W. A. Harvey. 1965. Chemical control of woody plants in California. Revision of Calif. Agr. Expt. Sta. Bull. 812. 26pp.

29. Leonard, O. A. and A. H. Murphy. 1965. Relationship between herbicide movement and stump sprouting. Weeds 13:26-30.

30. Morton, H. L. 1966. Influence of temperature and humidity on foliar absorption, translocation, and metabolism of 2,4,5-T by mesquite seedlings. Weeds 14:136-141.

31. Native trees of Canada. 5th ed. Dept. Northern Affairs and National Resources. Forestry Branch. Bull. 61. 293pp. 1956.

32. Parr, J. E. and A. G. Norman. 1965. Considerations in the use of surfactants in plant systems: a review. Bot. Gaz. 126:80-85.

33. Sargent, J. A. 1965. The penetration of growth regulators into leaves. Ann. Rev. Plant Physiol. 16:1-12.

34. Schwartzbeck, R.A. and M. G. Wiltse. 1964. A new herbicide, 4-amino-3,5,6-trichloropicolinic acid (Tordon) for brush control in the Northeastern Unitied States. NEWCC 18:414-429.

35. Steel, R. G. D. and J. H. Torrie. 1960. Principles and procedures of statistics. McGraw-Hill Book Co.

36. Watson, A. J. and R. J. Mesler, Jr. 1964. Effect of Tordon herbicide as basal frill and tree injection treatments on certain hardwood trees. Down to Earth 19(4):20-23.

37. Watson, A. J. and M. G. Wiltse. 1963. Tordon for brush control on utility right-of-way in the eastern United States. Down to Earth 19(1):11-14.

38. Wiltse, M. G. 1964. Tordon herbicide as a soil treatment for brush control. Down to Earth 19(4):3-6.

APPENDIX

Table 1. Details of herbicides used

Common name	Chemical name	Source
Picloram	Potassium salt of 4-amino-3,5,6-trichloropicolinic acid.	Dow Chemical of Canada, Ltd., Sarnia, Ont.
Tordon 101	Mixture of 20% picloram and 80% of 2,4-D present as amine formulations.	Dow.
2,4-D amine	Dimethylamine of 2,4-dichlorophenoxyacetic acid	Amchem Products, Inc., Ambler, Pa.
2,4-D ester	Ethyl ester of 2,4-D	Amchem.
2,4-D emulsamine	Dodecyl amine salts and tetradecyl amine salts of 2,4-D.	Amchem.
2,4-D acid	A special form of emulsifiable 2,4-D acid.	Amchem.
2,4-D salt	Coded formulation	Pennsalt Chem. Co., Tacoma, Washington.
2,4-5-T	Iso-octyl ester of 2,4,5-trichlorophenoxyacetic acid.	Chipman Chemicals Ltd. Edmonton
Silvex	Propylene glycol butyl ether esters of 2-(2,4,5-trichlorophenoxy) propionic acid.	